IMMEDIATE COST-EFFECTIVE ABATEMENT OF WATER POLLUTION FROM NAVY SHIPS

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by

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CHAPTER ONE
INTRODUCTION

I. BACKGROUND

This paper was written by the Naval Postgraduate School
Pollution Study Group, twelve officer students at the Naval
Postgraduate School, Monterey, California. The uniqueness
of the group stems from the fact that its members combine
the academic disciplines of electrical and mechanical
engineering, management, oceanography, and operations
research with an average of eight years of Naval service.
Thus the academic techniques of investigation may be com-
bined with operational experience to provide more useful and
viable recommendations. The operational experience of the
group lies primarily in shipboard operations. Dr. John Huth,
Special Assistant to the Director of Navy Laboratories,
sponsored the group which is under the direction of Dr. C.F.
Rowell, with academic advisors from the departments previ-
ously mentioned.

The Navy has made long range plans for its attack on all
aspects of pollution. The study group was charged to
impartially investigate aspects of these plans, and, if
possible, to recommend and evaluate alternative solutions.
The group was also to study possible short-term measures

to provide immediate solutions pending implementation of the long range plans.

The Navy effort, and indeed that of all Federal agencies, is the result of both recent legislation and a recognition of the need for environmental protection. Legislation actually began with the 1899 Refuse Act; however the Navy is now operating under the 1961 Oil Pollution Control Act, the 1970 Water Quality Improvement Act and State and local regulations. In addition, Executive order 11507 directs that all Federal Agencies shall take the lead in combating pollution. Direction is provided for the Navy in OPNAV Instructions 6240.3 and 6240.4 series and is further amplified by various local instructions and directives.

The decision to limit the group's efforts to abatement of oil and sanitary waste-caused pollution was based on the overwhelming significance of these as Navy problems and the important interactions with the students' shipboard experience.

II. SHIPBOARD WASTE DISPOSAL

Disposal of sanitary wastes aboard U.S. Navy ships has been simple for a long time. Waste was simply dumped overboard, whether on the high seas where dilution and nature were assumed to quickly disperse the waste, or in small restricted harbors with little or no circulation. Public awareness, as reflected in legislation and directives listed

above, required that the Navy proceed on several fronts.
These plans of attack appear in some cases to be coordinated
efforts to divide the problem and combat its several areas.
In other cases, separate efforts have been made in devising
many different competing systems that operate either simul-
taneously with a good deal of duplication or consecutively,
with each new system being replaced as soon as a better one
becomes available. In this report, the various systems are
examined, with particular consideration to temporary systems
for rapid implementation.

Some important considerations in the selection of a tem-
porary system are extent of temporary solution desired, time
to implement, and ease of transition between the temporary
system and the "permanent" system. Actually, these factors
are of major importance in any system, especially in the
field of Navy waste disposal where changing regulations and
technology seem to put nearly all systems in the temporary
category. At the very least, they will be interacting with
other systems later.

Several long range plans for sanitary waste disposal are
compared and discussed. These include the various on-board
treatment plants, the project of putting municipal sewer
extensions on piers in several Navy ports to serve 24 large
class ships, and the concept of on-board holding tanks.
Expansions and modifications of these plans are suggested
and examined with a view toward broader or more immediate
applications, centered around a simple transfer system for

discharging waste to off-ship receiving facilities. Various
temporary systems for immediate implementation are discussed.

III.   FUEL AND WASTE OIL SPILLS

Each year, the United States Navy, either accidentally
or through neglect, pumps many gallons of fuel and waste
oil onto the high seas and into the waters of our ports and
harbors. It is necessary, but not enough, that the Navy
provide for the cleanup of these spills. Efforts must also
be undertaken to prevent such discharges at their source.
This study addresses these problems and offers some recom-
mendations in the areas of oil spill prevention and cleanup.

Several basic physical and operational facts are needed
to proceed with any rational regulation and control.

Estimates of solubility, toxicity (relative), spreading
characteristics, vertical mixing as a function of turbulence,
and the distribution of oils in bilge contents were made
through laboratory examination. It was also noted that the
age of an oil spill could be determined readily for contract
monitoring. A search for temporal significance of oil spill
occurrence was sought and some periodicity noted. No clear-
cut correlation to any operational situation was made,
however.

Efforts to examine fueling processes to reduce spills
led to design and specification of several improvements both
to handling systems and to operational guidelines.

Oil spill recovery was examined for the specific area of San Diego and its contingency plans and a more general management analysis with regard to proper strategy for balance between in-house and civilian capabilities.

CHAPTER TWO

CONCLUSIONS

In this chapter only major recommendations for immediate implementation are indicated. Many additional ideas are included in the detailed studies in the chapters that follow but were not included here in order to avoid obscuring the major conclusions.

I. RECOMMENDATIONS FOR DISPOSAL OF SANITARY WASTE

In the immediate future it is recommended that a system (discussed in Chapter Three) for grinding and pumping of sewage be installed on existing Navy ships as a common first step to a number of possible later stages or strategies of treatment. Such a system, which can be installed for approximately $22,000 per destroyer, would be used to transfer the waste to barges or bags until such time as pier hookups become available. Should R&D produce an on-board treatment system which is satisfactory, this subsystem is easily integrated.

Before great quantities of funds are expended in further development efforts toward on-board treatment systems, a number of questions, which range from the effect of chlorinated sewage on the environment to the basic process limitations in the various proposed treatment modes, might well

be addressed. Studies of process parameters will most probably lead to less expenditure of development funds and have a greater long range effect on treatment.

II. RECOMMENDATIONS FOR DEALING WITH OIL POLLUTION

A. SPILL PREVENTION DURING FUELING

The greatest number of spills and, by many orders of magnitude, the most oil spilled by the Navy is the result of fuel handling. Within this subset, overflowing tanks is the most significant problem.

Three complementary approaches are recommended; improved on-board indication and control (Chapter Eight), changes in regulations and, at least for San Diego, a change in the mode of fueling operation (Chapter Nine).

The first approach concerns minimizing the number of fuel oil tanks that overflow overboard and implementing effective indication and control measures on these tanks. The recommended improvements in indication and control consist of installation of accurate level indicators, installation of remote indicators at a central location, and provision for an emergency shut-off capability for the fuel transfer pumps from the central monitoring station. The price for this proposal, including labor costs for installation, for all ships of the Cruiser-Destroyer Force will be in the neighborhood of six million dollars. It is projected that the number of overboard oil spills will be reduced by 70-90% (depending on the data basis used).

A second significant change would cost nothing for initial implementation and probably little in use. The recommendation is to lower the maximum fueling level from approximately 95% to 90% and the required refueling level from 85% to 75%. The degradation in readiness is small (~5% of range) and the risk of overfilling is very markedly reduced.

The third change in operating procedures involves the elimination of oiler transfers to ships in harbors. The major reason for this recommendation is the notably lower number of spills from fuel pier refuelings; but the cost for such a change, which would involve building another fuel pier for San Diego, was found to pay back its initial investment in less than two years.

B. SPILL CLEANUP

Our recommendations in this area are related primarily to questions of the balance of equipment needed for an in-house Navy team and the best balance between contractor and in-house clean up.

By analysis of oil spill logs, in a manner that is applicable to other sites as well, it was shown that the Eleventh Naval District plan for San Diego was very good as to the proper location of spill control crews. The nature of the area to be covered by these crews was examined and recommendations for equipping each crew are made. The equipment will vary with location to be cost-effective.

An analysis of the cost of oil pickup equipment and personnel as a function of time and a similar projection of the effects of pollution abatement strongly support an argument for use of contractor services for all Navy oil cleanup. Not only is this the most cost-effective but it also maintains a civilian capability for other use.

C. BILGE AND BALLAST WASTE

Examination of the concentrations of oil in bilges, its toxicity as reported in the literature (as low as 20 ppm in a chronically polluted, unflushed slough) and the state of the art with respect to treatment of dissolved oil suggests that there are a number of policy questions to be answered. It appears that open ocean dumping of the bilge waste while under way has a negligible or small biological effect on the ocean. Current separation techniques do not use principles that can deal with oil components that are truly dissolved. Transfer ashore with improvement over current practice seems to be the most appropriate method for the foreseeable future. R&D to develop new techniques that work at this level of dispersion should be supported. Some biological efforts in this regard seem promising as does the use of a wet oxidation system similar to one available for sewage treatment. Toxicity of contaminants limits the first; materials problems the latter.

III. SUMMARY

The following table summarizes our immediate recommendations:

AREA	PROGRAM	COST	ESTIMATED EFFEC-TIVENESS	REMARKS
S E W A G E	Install transfer system	$22 K/DD (~$5 million*)	Depends on the next stage; removes much of the most expensive part of future reconfiguration.	
	Proceed with transfer ashore	$2,394,000**		
O I L	Install Shipboard Central Fueling Station	$5-6 million*	70-90%	Also improves engineering operations
	Maximum-minimum fueling change		Up to 84%	
	Fueling pier utilization	$982,325** (Investment paid off in two years)	23-48%	Better crew preparedness for refueling aboard ship
	Convert to all contractor cleanup	Cost reduces with improved spill prevention	--	Better civilian service results
	Bilge-ballast shipped ashore	No new expense	100%	

*All Cruiser-Destroyer Force
**Calculated for San Diego as model

CHAPTER THREE

SHIPBOARD CONTROL OF WASTES

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Abstract: The large variety of sewage treatment plants capable of being installed on-board Navy ships is examined and evaluated. The alternative of installed holding tanks is discussed, from large tanks to individual portable facilities. A system is proposed whereby Destroyer type ships can transfer all sewage directly ashore. Finally, ashore receiving facilities are discussed, including portable storage tanks, storage and treatment barges, and pier connections to city sewer systems.
It is concluded that the most efficient method of handling wastes, barring open-ocean restrictions on discharge, is to install a simple grinder/transfer system aboard ship and discharge to sewers where available and to a barge or portable tank otherwise.

I. INTRODUCTION

There are basically three ways of disposing of sanitary wastes generated aboard U.S. Navy ships. All of these have been tried in the Navy to some degree, and systems are under development that incorporate each approach. The methods are: (1) treatment on-board and discharge into the environment; (2) hold on-board for discharge into open waters or off-ship receiving facilities; (3) discharge directly into connections to off-ship facilities.

The treatment utilized prior to discharge in the first scheme has varied a good deal, as have the requirements for

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treatment. The majority of ships now treat only by dilution with flush water before discharging. Various treatment systems that treat to varying degrees, have been proposed and tested by numerous manufacturers. Standards for effluents are being made and revised almost constantly. The Fairbanks-Morse Unit, a treatment system tested extensively by the Navy, was designed to meet standards of 50 mg/l. Biochemical Oxygen Demand (BOD), 150 ppm suspended solids (SS), and 1000/100ml total coliform. The EPA proposed standards are 100 mg/l, 150ppm and 240/100ml. Anticipating more stringent requirements, the Navy has set NAVSEC Research and Development contract specifications at 50 mg/l, 80ppm, and 240/100ml [NAVSHIP ENG CEN, 1971].

The second method--holding on-board--requires a large capacity holding tank to be installed on the ship. All sewage is diverted to the tank until discharge is possible. This implies that only discharge into coastal and harbor waters is stopped, and that some means of receiving sewage periodically, typically a barge, portable treatment facility, or pierside sewer is available in Navy ports.

The third approach (and the second to some extent) requires a transfer system on-board the ships. For direct discharge, connections from the ship would be required throughout the vessel's stay in port. These could be to external holding tanks or barges, or to a sewer connection on the pier.

II. SHIPBOARD TREATMENT OF SANITARY WASTE

A. PRELIMINARY CONSIDERATIONS FOR SHIPBOARD SYSTEMS

The shipboard environment quite often prohibits the effective use of waste water procedures and processes practiced ashore. Limitations in weight and space, power demand, location of equipment, preservation of watertight integrity, effects of the saltwater environment and finally maintainability, operability, and reliability of equipment and its effect on habitability are factors to be considered in the design of shipboard systems.

The limitation of space and reserve buoyancy to support added weight is common to all vessels but probably moreso to vessels of war. The placement of machinery, weapon systems, the allocation of spaces for berthing, messing and operations have been taken into account in ship design in order to maintain metacentric stability. Although topside spaces could be made available for sanitary treatment devices, the addition of weight high in a vessel raises its center of gravity and makes a vessel more susceptible to capsizing.

As a consequence, permanently installed units should be placed low in the hull of a vessel. The placement of such equipment consequently may affect the location of machinery, equipment, and spaces originally designed into the ship. In general, space in the lower regions of a naval vessel is allocated to propulsion and power machinery, and in some cases for weapon support equipment such as sonar. Space is

at a premium and little, if any, non-vital equipment is found. Maneuverability for maintenance and watchstanding personnel is also taken into account in design for easy and adequate access to equipment as well as for damage control considerations. To make room for additional equipment may require relocation or removal of vital machinery, which in turn affects the metacenter.

Installation of sanitary systems on older vessels will require, in general, the rerouting of plumbing systems. At present, sanitary piping is designed for the most direct route overboard with little if any unnecessary penetration of additional compartments prior to discharge. New piping may involve the penetration of several watertight bulkheads, which degrades the watertight integrity of a vessel. Additionally, the power balance aboard a vessel is a critical factor in the design of equipment installed on-board, and any additional equipment having power needs must be compatible with existing power capabilities of a vessel, especially during peak power demand. Preliminary design of new-construction ships can take the above considerations into account and alleviate the problems mentioned.

Another consideration of equipment design is the motion of a vessel. A ship pitches and rolls--sometimes very drastically--with sea and weather conditions. At the same time, shocks occur quite often due to the slamming of a vessel's bow into the waves. This results in vibrations being carried throughout the vessel. Shipboard equipment is

designed with these considerations in mind and is tested
prior to actual on-board installation. Treatment systems
may not be required to operate at open sea at peak effi-
ciency, but they must be seaworthy enough so that ship
motions do not damage the equipment resulting in improper
performance in port.

The saltwater environment can have detrimental effects
internally and externally on all shipboard equipment, thus,
equipment must be designed to minimize corrosive effects
and prevent contamination.

Finally the factors of maintainability, operability,
reliability, and habitability must be adequately considered.
The equipment must be simple enough for shipboard personnel
to maintain and expeditiously determine and correct failures.
The system should be designed for easy accessibility. Pro-
vision should be made by the manufacturer for adequate
repair parts and technical manuals to permit effective
operation, maintenance, and repair. Considerations of
backup systems should also be taken into account. Habit-
ability considerations include noise, heat, vibration, odor
and emission of toxic fumes. Performance measures to
evaluate shipboard treatment systems on these factors as
well as on actual processing capabilities should be estab-
lished and followed.

B. OBJECTIVES OF ON-BOARD TREATMENT SYSTEMS

The following objectives should be met by on-board
sewage treatment systems:

a. Shipboard systems should be able to handle any size or consistency of fecal matter.

b. The flushing system should be compatible with the treatment process and rate of process and vice versa.

c. Shipboard systems should be insensitive to the temperature and chemistry of the flush.

d. Systems should be capable of modification by means of effective field changes or alterations to adequately comply with new minimum effluent quality standards whenever revised.

e. Shipboard wastes to be processed should include all sanitary and domestic wastes--human, laundry, shower and galley wastes.

f. Standardization of treatment systems should be sought in order to standardize repair parts.

g. Systems should be easy to operate and maintain. Basic schooling and/or on-the-job training should be all that is necessary to keep the systems on the line.

h. Systems should be resistant to abuses by shipboard personnel, such as foreign objects being thrown into commodes.

i. Most importantly, the quality of effluent should at least meet, and preferably surpass, EPA standards for BOD, SS, and coliform.

C. ANALYSIS OF SHIPBOARD SYSTEMS

Two general categories of wastewater treatment systems have been installed on vessels--biological and non-biological. Biological systems utilize the bacteria in waste to aid the decomposition process while non-biological systems use other means to dispose of organic compounds.

1. Biological Systems

In an anaerobic digestion process, once the entrained oxygen supply is exhausted, anaerobic bacteria take over from the aerobic bacteria in the decomposition process and produce putrefactive changes. Anaerobic treatment systems have been tried on vessels with unsatisfactory results due to the production of noxious and toxic gases and highly corrosive by-products [Maritime Information Committee, p. 46, 1971].

The influent of an aerobic digestive system is first comminuted to break up solid components to fine particles, thus enhancing the oxidation of material in an aeration tank where air is diffused through the mixture. The excess air, mixed with the gaseous products of oxidation, exhausts through the vents at the top of the tank. Separation of sludge and liquid is accomplished in a settling chamber with the settled sludge returned to the aeration compartment for further aeration while the liquid is mixed with a disinfectant before overboard discharge.

Aerobic bacteria require proper care and feeding. When ample supplies of food and oxygen are available, the

bacteria thrive and multiply and do their job well. Shore
installations alleviate shock loading by pacing with tanks
and pumping schedules to maintain continuous feeding and
oxidation. Pacing would be even more important with a small
shipboard system where it is necessary to avoid shock
loadings three times a day during crew's messing periods.
The system must be in operation continuously for the bacteria
to survive, consequently the system would be running at all
times in port and at sea and would have to be continuously
watched and maintained carefully. New studies, however,
have indicated that the reduction of food has little effect
on a system's capability to reinitiate growth [Guss, 1971].
In addition, aerobic bacteria performance is sensitive to
temperature--performing more efficiently at higher temper-
ature. The efficiency of the process is reduced, however,
by the ship's motions that tend to disrupt the settling
process; this could result in carry-over of solid particles
with the separated liquid. This is not critical in open
waters, however, where effluent standards have not as yet
been prescribed. In general, biological systems are heavier,
occupy more space, and require longer periods to adequately
treat wastes than non-biological systems.

The cost of the plants and their installation is highly
variable. The Maritime Administration provides the average
total cost figures shown in Table 3-1.

In 1969 the Army Corps of Engineers conducted studies to
evaluate the extended aeration sewage treatment plants on

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TABLE 3-1

Cost of Shipboard Sewage Treatment

[Maritime Information Committee, 1971, p. 48]

NO. SHIPS	CAPACITY (men)	TOTAL COST/SHIP ($1000)
23 in operation	24 to 50	$48 to $50
15 new construction	50 to 83	$50 to $55
8 conversions	50	$80 to $90

three Corps-owned dredges [U.S. Dept. of the Interior, 1969].
The results indicated that the performance of the treatment
plants was unsatisfactory because current BOD, SS and coli-
form standards set by the U.S. Public Health Service were
not consistently met. The analysis was based on the three
plants' performance, however, and malfunctions experienced
in one engineering configuration cannot support a general
conclusion concerning shipboard biological systems. Ship-
board pilot plant studies on two biological systems which
have the highest probability of meeting desired objectives
have been recommended [Guss, 1971]. These are an extended
aeration activated sludge system and a rotating bio-disc
system.

2. Non-Biological Systems

One of the first systems for small craft was the
macerator/chlorinator. The system grinds the waste into
small particles, disinfects it by chlorination and then
discharges it overboard. It alters the appearance of the

effluent (making it less offensive and killing disease-bearing bacteria), but the decomposition process continues after discharge and the system does not reduce BOD and suspended solids [Maritime Information Committee, 1971].

In electromechanical sewage treatment systems the influent first enters a device that mechanically separates gross solids, and the solids are then transferred to a sludge tank. Suspended solids are removed from the liquid by electro-coagulation or by hydrogen flotation. A floc is formed that is skimmed and transferred to a sludge tank. The liquid is then disinfected by chlorine, or exposed to ultraviolet light prior to discharge. The sludge may be chemically treated or temporarily stored for later disposal, or may be transferred to an incinerator for burning.

In general, electro-mechanical systems are smaller and lighter than aerobic systems and are more compatible to shipboard installation. However, they are normally more expensive and more importantly, have little effect in reducing dissolved BOD in the effluent.

The principle of operation of a mechanical-chemical sewage treatment system is similar to that of electro-mechanical systems except that alum and ferric chloride are used to coagulate the solids. Similarly, BOD in the urea-containing effluent is reduced insignificantly.

Another treatment technique uses evaporation where liquids are evaporated and then solids are dried, sterilized, or incinerated, using gas as a fuel. One such system

requires a reduced flush and has provision for continuous deodorization of the exhaust gases [Maritime Information Committee, 1971].

Other techniques such as filtration and wet oxidation will be described under particular systems evaluated.

In general, non-biological systems are more expensive but are more compact, weigh less, and are more compatible to ship-board life than biological systems. However, some will not accept all domestic waste or operate with a salt-water flush. Most systems have been designed to meet only present EPA standards--as yet no systems tested on-board have consistently achieved these standards, which could be replaced later by even more stringent requirements.

D. CURRENT SYSTEMS UNDER EVALUATION

The ultimate goal for on-board treatment is the Ship-board Integrated Disposal System, which would handle all wastes--sanitary, domestic, solid and industrial [Lee, 1971]. Preliminary action towards this goal has been the support in development of shipboard treatment systems by five manu-facturers: Fairbanks-Morse, Chrysler, Koehler-Dayton, Thiokol, and Dorr-Oliver. These systems, as well as nine others, will be discussed in the following paragraphs under the categories of biological and non-biological systems as described in general previously.

1. Biological Systems

General Dynamics (Dorr-Oliver) utilizes a biological process with membrane filtration. Raw sewage is aerated

continuously in a holding tank which functions as a completely mixed biochemical reactor. The slurry removed from the holding tank is macerated and pumped through a membrane filter system which traps molecules with a molecular weight in excess of approximately 150. The remaining liquid, containing all of the soluble BOD, is discharged. The filtrate is recycled to the holding tank. A small fraction of the solids from the holding tank (sewage solids and biomass) is pumped to another aeration tank of the same size where it loses weight by auto-oxidation and by evaporation. The bacteria present die and serve with residual fecal solids and paper as food for surviving bacteria. A small volume of bacterially non-digestible sludge from the second tank must be disposed of at one-month intervals.

The system is unique in its use of filtration membranes which prevent carryover of solids with the effluent. It does have the requirement, like all biological systems, of sludge removal. At monthly intervals, the sludge can be pumped overboard in open waters, or to a sludge collection barge or tank truck. The system as designed at present will handle only human wastes. Additional information is provided in the summary table at the end of this section.

Four other systems analyzed use biological treatment processes to handle wastes. They are the Pall Trinity Micro Model MPT 6000, the Peters Marine Sewage Treatment units, the FRAM Marine Waste Treatment unit and the Aquanox Mariner Treatment Unit. In general, all of these rely on extended aerobic treatment.

The Pall Trinity unit has been installed on the Sewage Treatment Barge (YFN-1249) for evaluation of treatment of submarine waste in New London, Connecticut. Originally, the system was to be evaluated from November 28 through December 10, 1971. However, due to contract problems with operating personnel, the evaluation has been postponed until 1972. The Pall Trinity Corp. is to manufacture up to 27 units for installation in the new High Speed Attact Transport (LHA) ships, three units (of 300-man capacity each) for each ship. The prototype is larger than the Fairbanks-Morse unit, but equipment is easily accessible for maintenance and monitoring. The company claims that "once-a-day" operator attention, which involves a one or two minute "walk around" inspection, is required. The plant on YFN-1249 will handle only human waste.

G. D. Peters & Co., Limited, of Slough Bucks, England has provided all sewage treatment plants currently in operation for the British, Australian and Canadian Navies. Although carryover of solids with effluent is not a problem while in port or at anchor, quiescence is normally required in the settling tank at all times to affect solid-liquid separation. The company has minimized the slopping effect by trapping the surface of the settling tank. The plants are custom designed and will differ depending on the size of the ship and the degree of shock resistance required. A cost estimate for a 60-man unit is approximately $15,000, while that for a 120-man unit is $25,000. These estimates

are probably based on installation rates in Great Britain and might be expected to be doubled or tripled in the United States.

In the FRAM Marine Waste Treatment System, solids are separated from liquid by means of a vibrating screen. As the solids build up they are discharged to an incinerator for combustion. The liquid is heated, aerated and is recycled through an aerobic settling tank to reduce BOD and suspended solids before being disinfected and discharged. The system is available in 20, 50, 100 and 200-men units. All systems are modular in design, mounted on skids, and are piped and prewired to facilitate installation within existing or new ships. The 200-man unit would occupy approximately 500 cubic feet and weigh 7,500 lbs. The cost of a 200-man unit built to Navy specifications, not including any special Navy test requirements, would be $50,000, while a 50-man system would cost approximately $35,000.

The Aquanox Mariner treatment system utilizes a controlled oxidation process for wastewater treatment which accelerates the normal breakdown rate of the organic wastes found in sewage. Comminuted waste is pumped into an oxidation tank where it is thoroughly aerated. Here it is clarified and transferred to a flotation tank where floatable solids and heavy particles are recycled back to the oxidation tank while the remaining liquids are drained off for disinfection prior to overboard discharge. Sludge must be removed periodically.

An Aquanox Mariner 50 unit has been installed on the sewage treatment barge (YFN-1249) for evaluation of treatment of submarine wastes in New London, Conn. The cost of the 3-ton unit for 200-men is $4,000. Like the Pall Trinity unit discussed previously, it has not yet been operated. It is compact and comparatively inexpensive. It does not provide, however, for easy accessibility for maintenance.

2. Non-Biological Systems

a. Electro-mechanical

Three systems fall in this category--Fairbanks-Morse, General Electric and Environment/One. All three systems are similar in operation except that the Fairbanks-Morse unit relies on gravity feed and thus must be located in the lower areas of a vessel. The latter two units are outfitted with a combination macerator-pump located near the ship's head and thus allow positioning of the treatment unit in areas other than engineering spaces.

(1) Fairbanks-Morse System--A Study in Futility. The contract for the Fairbanks-Morse unit was originally awarded on 8 April 1966. A 175-man unit was first evaluated on the USS FISKE (DD 842) in March 1968 and subsequent units were installed on the USS CANOPUS (AS-34) in November 1969. While laboratory evaluation of the system indicated a good probability of successful shipboard operation, actual shipboard installations have fallen short of required goals. Three 500-man units were installed on the USS FULTON (AS-11) during its regular overhaul in April 1971. Although the

units cost $100,000 each, the cost of repiping the ship was $1.2 million and an additional $900,000 was required to relocate equipment from space taken by this system as well as for an internal manifold system for pierside transfer of sewage [Lee, 1971]. A technical evaluation of these units was conducted during the period 7 September through 22 November 1971. Many material problems required immediate correction and dropped the reliability and maintainability below the goals set for acceptance of the equipment. The mean time between failure of the system was 191.7 hours, and the mean time to repair was 2.6 hours [Singerman, 1971].

Data available through 29 October 1971 indicates that the current model of the Fairbanks-Morse Unit cannot meet the proposed EPA effluent quality standards. Analysis of suspended solids showed that each unit met EPA standards an average of 94% of the time. With respect to effluent BOD, the EPA standard was met only 66% of the time [Singerman, 1971]. During the operational evaluation and the period following, the performance of all three units continually degraded. Although the effluent coliform count was met always, the BOD of the effluent met proposed standards three times out of 143 samples while SS met standards only 25% of the time as indicated in the analytical logs from the USS FULTON (AS-11). In general, no electromechanical system can effectively reduce the BOD permanently in urea containing effluent which is separated and ultimately disinfected and discharged.

The Fairbanks-Morse Unit can process 15,000 gallons of raw sewage per day. It has been estimated that the annual preventive maintenance cost for the three units will be $185,000 and the annual corrective maintenance cost $17,000 [Piersall, 21 September 1971].

A large amount of time and money has been expended trying to rectify problems involved in all Fairbanks-Morse prototypes evaluated.

(2) General Electric and Environment/One Systems. In the General Electric and Environment/One systems the treatment units are basically similar, perhaps in part because a number of the latter company's staff originally worked on the General Electric system. The combination macerator and pump performs the functions of maceration and comminution and facilitates pumping the slurry through relatively small-diameter piping and annular spaces over great distances and fairly high elevations (e.g. 3000 ft. at a head of 81 ft.). The pump is located in the head area and thus allows treatment units to be located elsewhere.

In January 1971, General Electric installed a $228,000 prototype on the 370-ft. US Army Dredge, GERIG, which works along the southern states. The system will handle the sanitary and kitchen wastes of 50 of the 100-man crew. Two other units are on two ore carriers on the Great Lakes--the SS JOHN G. MUNSON and the SS LEON FALK, JR. The Destroyer Development Group in Newport plans to evaluate the G.E. system on the Newport-based destroyer, USS KOELSCH (DE-1049).

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It is planned to install the plant topside to avoid diffi-
culties attendant with installation below decks. One head
and all galley waste will be connected to the processing
unit by flexible hose through the pump-storage-grinder
located in the head. The USS KOELSCH (DE-1049) will deploy
on 10 March, 1972 with the unit installed on board by ship's
force. The system will be operated and evaluated during an
entire Mediterranean deployment. The cost for a 150-man
unit is $50,000. The total estimated system cost is $70,000
for the KOELSCH installation.

b. Electro-Chemical

Two systems manufactured by Thiokol and FMC fall
under this general description. In the Thiokol unit coarse
solids are removed from the raw sewage by means of a screen.
The residual solids are centrifuged, with the remaining
concentrate and coarse solids directed to an incinerator.
The separated fluid which contains residual suspended solids
and some organic matter is directed to an electrolysis cell
which generates sodium hypochlorite, an oxidant which attacks
the bacteria. The effluent is then irradiated with ultra-
violet light prior to discharge.

This technique is being studied under a $584,000 contract
to be conducted in three phases. Phase one funding began
in September 1971 and covers laboratory development and
demonstration of a prototype marine waste treatment system.

In the unit designed by the FMC Corporation, Ordnance
Engineering Division, a bactericidal agent is added to the
comminuted solids in a surge tank to stop pathogenic growth.

The sewage is then treated with chemicals and passed through filters where the solids are retained for disposal by incineration or placed in containers for disposal ashore and the liquid discharged is disinfected. The company has successfully demonstrated a pilot plant on board the YFND-43 Barge, a support Vessel for the MK I Deep Dive System, at Norfolk, Virginia.

c. Recirculation

Chrysler, Koehler Dayton, and Elsan Ltd. produce units that rely on reduced flush/recirculating systems.

Instead of water, the flushing medium of the Chrysler system is transformer oil, a low-density bacteriostatic organic fluid. The specific gravity of the oil is much less than that of feces and urine, thus enabling separation by settling [Lee, 1971]. The oil is bacteriostatic and dermatologically harmless. The wastes and the flushing medium are separated by means of a filter and holding tank. The sludge is macerated and then directed to an incinerator for combustion. The flushing medium is passed through micron filters resulting in a clean flush ready to be used again. The residue concentrate also is directed to the incinerator. The system, due to its complete combustion process of all fecal and urine wastes should result in meeting all EPA standards.

The Chrysler unit was developed with the support of the Navy for $65,000. The system is to be ready for laboratory tests in May 1972. It is relatively small in volume but

considerably heavier than most units. Complexity of opera-
tion and maintenance requirements are unknown.

In the Koehler Dayton unit, raw sewage utilizing special
toilets, provided with a water supply sufficient for initial
flushes, is concentrated in a boiler where most of the
biological activity is destroyed. The distillate is recir-
culated for flushing. The concentrate is stored up to 40
days and then pumped to an incinerator for complete combus-
tion of wastes.

The contract for development of the system was awarded
23 March 1970. Special toilets would be required to replace
existing ones and thus require use of the system at all
times. As with the Chrysler unit, only human waste is
expected to be processed. The complexity of maintenance
is unknown.

Elsan Sewage System, Ltd., of London, England has
developed a system for shipboard use which uses a reduced
flush made up of recirculated fresh water and disinfected
fluid wastes. The solid wastes are macerated, disinfected
and stored for later disposal ashore or at sea. The system
does not provide for any treatment of waste with the excep-
tion of reducing the coliform count. However, the existence
of such a system as configured may indicate that a no-
effluent policy could be implemented in British ports which
would result in the requirement of pierside hookup
capability.

d. Wet Oxidation

In a wet oxidation unit waste water is comminuted
and then pumped through a heat exchanger into a reaction
chamber where enough residence time is provided to oxidize
all organic material. The processed wastewater is returned
through a heat exchanger to recover heat and then it can be
recycled for reuse in flushing, refuse pumping, or discharged
overboard. Zimpro, Inc. has been awarded a contract to
develop a unit to provide a total integrated disposal system
such that wastepaper (classified documents), galley, sanitary
and domestic wastes, in addition to bilge water and oil
mixtures, will be processed. A problem arising with the
system is the lack of structural materials that can persist
under conditions of high temperature and salt water. A
300-man unit is to be evaluated at the U.S. Naval Academy
Enlisted Men's Barracks in a one-year test.

E. SUMMARY

Table 3-2 provides a summary of the major characteristics
and engineering specifications of the 14 systems examined.
Table 3-3 indicates what objectives specified in section
II-C are met by each system. Data in Table 3-4 provides a
normalized specifications for assistance in evaluating
systems on a per-man basis. In addition, the table provides
a research and development priority listing based on this
report's analysis of the systems considered. The classifi-
cations, ranging from highest to lowest, are as follows:

TABLE 3-2

General Characteristics of Selected Shipboard Treatment Systems

GENERAL TECHNIQUE	SYSTEM	TYPE WASTE HANDLED	CAPACITY (men)	SIZE (FT3)	WEIGHT (LB)	INITIAL COST PROTOTYPE ($1000)	REQUIRES REPIPING YES/NO	REMARKS
BIOLOGICAL	Dorr Oliver	Human	200	232	16,000	Unknown	Yes	On YFN 1249
	Pall Trinity	Human	200*	1300	36,000	22	Yes	British prices quoted
	Peters Marine	All $ Domestic	60	345	Unknown	15	Yes	
			120	Unknown	Unknown	25		
	Fram	Sanitary $$	50	Unknown	Unknown	35	Yes	
			200	500	7,500	50		
	Aquanox	All Domestic	200*	294	6,000	4	Yes	On YFN 1249
	Fairbanks-Morse	Sanitary	500	855	18,000	115*	Yes	On USS FULTON
ELECTRO-MECHANICAL	General Electric	All Domestic	50*	585*	10,000*	228*	Yes	On Dredge GERIG, SS MUNSON, SS L.FALK
			150**	600**	12,000**	50**		
	Environment/One	All Domestic	Unknown	Unknown	Unknown	Unknown	Yes	Still in development stages
ELECTRO-CHEMICAL	Thiokol	Human	200	120	6,000	175 (funding)	Yes	
	FMC	All Domestic	50	80	900	27	Yes	On YFNB 43
			100	90	Unknown	31		
RECIRCULA-TION	Chrysler	Human	200*	60*	40,000*	65 (funding)	No	#Size of incineration only
	Koehler Dayton	Human	200	1-2#	1,500#	Unknown	No	Storage device only
	Elsan Ltd	Human	Unknown	Unknown	Unknown	Unknown	Yes	
WET OXIDATION	Zimpro	All Domestic	300*	448	Unknown	420 (funding)	Yes	To be tested at USNA enlisted men's barracks

*Prototype specifications.
**Installation on USS KOELSCH (DE-1049)
$All domestic includes sanitary and galley wastes.
$$Sanitary includes human and shower/sink wastes.

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TABLE 3-3

Objectives Met by Shipboard System

SYSTEM	WASTES HANDLED	INFLUENT TEMPERATURE/ CHEMISTRY INSENSITIVE	ABILITY OF SYSTEM CONCEPT TO MEET EPA EFFLUENT STANDARDS		
			BOD	SS	COLIFORM
Dorr Oliver	Human	No	Unknown*	Yes	Yes
Pall Trinity	Human	No	Unknown*	Yes	Yes
Peters Marine	All domestic	No	Unknown*	Yes	Yes
Fram	Sanitary	No	Unknown*	Yes	Yes
Aquanox	All domestic	No	Unknown*	Yes	Yes
Fairbanks-Morse	Sanitary	Yes	No**	No**	Yes**
General Electric	All domestic	Yes	?	Yes	Yes
Environment/One	All domestic	Unknown	?	Yes	Yes
Thiokol	Human	Unknown	?	Yes	Yes
FMC	All domestic	Unknown	?	Yes	Yes
Chrysler	Human	Unknown	Yes	Yes	Yes
Koehler Dayton	Human	Unknown	Yes	Yes	Yes
Elsan Ltd	Human	Unknown	No	No	Unknown
Zimpro	All domestic	Yes	Yes	Yes	Yes

*Company claims unit meets BOD standard.
**Based on Navy test data.
NOTE: (1) All systems can handle any size fecal matter.
       (2) All systems, with the exception of the recirculation type, are compatible with a saltwater flushing system although all are susceptible to saltwater corrosion.
       (3) All systems can be designed or modified to resist damage by foreign materials introduced by shipboard personnel.
       (4) Experience with the Fairbanks-Morse unit leaves a question on whether electro-mechanical systems can meet BOD standards.

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Table 3-4

Normalized Specifications of Shipboard Treatment Systems

SYSTEM	CAPACITY (MEN)	NORMALIZED SIZE (FT3/MAN)	NORMALIZED WEIGHT (LB/MAN)	SHIPBOARD TESTED YES/NO	NORMALIZED COST ($/MAN)	LOCATION SPECIFICATION ON SHIP	R & D PRIORITY CLASSIFICATION
Dorr Oliver	200	2.16	80	No	Unknown	Lower Levels	II
Pall Trinity	300	6.45	180	In progress	1090	Lower Levels	II
Peters Marine	60 / 120	5.77 / Unknown	Unknown / Unknown	Yes	250 / 208	Lower Levels	II
Fram	50 / 200	Unknown / 2.5	Unknown / 37.5	Yes	700 / 250	Lower Levels	II
Aquanox	200*	1.47	30	In progress	20	Anywhere Below Decks	I
Fairbanks-Morse	500	1.7	36	Failure	230	Lower Levels	IV
General Electric	50* / 150***	11.7 / 4.0**	200 / 80**	Yes	4570 / 333**	Anywhere Below Decks	III
Environment/One	Unknown	Unknown	Unknown	No	Unknown	Anywhere Below Decks	***
Thiokol	200	.6	30	No	875	Lower Levels	III
FMC	50*	1.6	18	Yes	540	Anywhere Below Decks	III
Chrysler	200*	.3	200	No	325	In Hear Compartment	II
Koehler Dayton	200	Unknown	Unknown	No	Unknown	In Head Compartment	II
Elsan Ltd	Unknown	Unknown	Unknown	Yes	Unknown	Lower Levels	IV
Zimpro	300*	1.49	Unknown	No	1400	Lower Levels	II

*Prototype specifications.
**Installation on USS KOELSCH (DE-1049).
***Unable to indicate priority due to unavailability of adequate data.

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1. Systems specifications and/or performance warrant accelerated study and evaluation or immediate initiation of investigation with directed funds.

2. Systems specifications and/or performance indicate difficulties in meeting proposed standards and objectives but they could be improved with time and effort correctly expended. Limited funding should be provided to continue or initiate study.

3. System specifications and/or performance indicate greater difficulties in meeting proposed standards and objectives. Government funds should not be allocated--however, encouragement should be given for pursuit in development.

4. Systems specifications and/or performance cannot meet proposed standards due to system inability or to unsatisfactory cost over-runs. Further study is not warranted and any existing contracts should be terminated.

F. CONCLUSIONS

No treatment system so far tested and evaluated has been found to satisfactorily meet EPA standards and to satisfy the rigorous requirements of shipboard operations. The Fairbanks-Morse unit has failed to fulfill goals established in two contracts awarded since 1966. This is in spite of an almost constant effort by the manufacturer's technical representatives working with only a small number of existing prototypes. In view of its material failures, inability to

consistently meet contract standards, and inefficiency in removing dissolved BOD, it is recommended that the Fairbanks-Morse contract be terminated.

All manufacturers of biological systems claim to meet EPA effluent standards, particularly in the area of BOD-- no system at present, however, has been shipboard tested and evaluated by the Navy. In electromechanical and electro-chemical units, the urea-containing effluent discharged overboard may meet SS and coliform standards but does not at present meet BOD acceptance levels and never will without alteration of the process. The recirculation systems have appeal in that BOD standards can be met, since all wastes are ultimately incinerated.

The only reasons apparent for continued efforts to develop an on-board system are (1) the requirements of foreign ports, (2) the inability to discharge into a municipal treatment system in the foreseeable future, and (3) the possibility of eventual prohibition of sewage discharge into the open ocean. Should this be the case, then further pursuit in development of systems as enumerated in the priority listing of Table 3-4 should be undertaken.

The Aquanox unit has appeal in its size, weight, cost, and processing capability. It has a major shortcoming of being perhaps too compact, thus, not providing sufficient accessibility for maintenance. However, its size and weight allow it to be located in areas below decks other than the lowermost regions of the vessel and linked to heads and

galley by means of a transfer system. Only through field testing will it be determined if EPA standards can be met. The recirculation systems have merit for possible installation on small craft under construction. However, the systems would not be acceptable on larger craft due to their restrictive capability of processing only human waste. A second system would be necessary if all domestic wastes were to be processed.

In conclusion, the accomplishment of satisfactory shipboard treatment of wastes cannot be realized now or in the forseeable future. The economics of on-board treatment systems suggest that further development be abandoned. If political considerations dictate the development of on-board systems, provision must be made for a significant period to do so without operational versions of these systems.

III. ON-BOARD STORAGE AND HOLDING FACILITIES

A. CENTRALIZED SHIPBOARD HOLDING TANKS

1. Background

The concept of ship wastewater disposal ashore implies that upon entry into coastal waters, all waste liquids are diverted from direct discharge overboard into a centrally-located on-board holding tank. The waste generated in transit and that generated inport would be disposed of off the ship.

The holding tank, as proposed by the Naval Ship Engineering Center (NSEC), would have a capacity to hold for a period of at least twelve hours. Booz-Allen Applied Research, Inc., in its report to the Naval Ships System Command [Booz-Allen, 1969], determined that a holding time of six hours is sufficient for normal transit in nineteen out of twenty-two port areas studied while the other three required twelve to fifteen hours holding time. These times are only estimates and, based on operational experience, some are quite high. Extended maneuvers in restricted waters might require a ship to hold wastes for longer periods, however.

Booz-Allen compared total and partial use of holding tanks, various types of treatment systems and special flush systems. The twelve concepts were evaluated using a set of normalized weighting factors and resulted in the centralized holding tank concept scoring the highest. However, factors such as degree of waste treatment and cost were not included in the characteristics of the twelve concepts.

2. Description of Centralized Holding Tank System

The centralized holding system consists of a large steel holding tank, shop fabricated and tested and installed as a complete unit aboard the ship. A comminutor is generally installed to comminute sewage solids to $\frac{1}{4}$ - inch particles prior to entering each holding tank. Each tank is equipped with two non-clog, 150-gallons-per-minute marine sewage pumps, connected in parallel, which discharge the sewage from the ship through discharge connections on the lowest weather deck.

3. Operation of the Centralized Holding Tank System

The system is intended to permit the following modes
of pollution abatement operation, based upon the operational
status of the ship:

a. When transiting restricted waters to unrestricted
   waters or to port, the system is used for sewage
   holding only. The tank is evacuated at sea after
   leaving restricted waters, or into a receiving
   facility after reaching port.

b. When in port, the unit can be permanently con-
   nected to a shore or barge receiving station,
   and automatically pumped when the tank is filled
   to approximately 80 percent capacity. Or, it
   can be intermittently connected to a receiving
   station for pumping.

c. At sea, sewage and wastewater are discharged
   overboard via the ship's drainage system. The
   collecting, holding and transfer system is
   secured.

The sewage is discharged by four-inch, rubber, smooth-
bore, light-weight buoyant hoses. The hoses are in 50-foot
lengths with the word "sewage" clearly stamped on each hose
at 10-foot intervals. Hose couplings are quick connect/
disconnect, cam-locking type with safety lock. The storage,
handling, maintenance and testing of the sewage discharge
hoses with fittings are the responsibility of the Naval
facility unless otherwise specified [Naval Ship Engineering
Center, December, 1971].

4. Cost Estimates for Equipment and Installation of
    the Centralized Holding Tank System

Booz-Allen estimated the cost of installation of a typical 175-man unit on a new ship and the cost of reconfiguring an existing vessel. The installation cost for tanks capable of holding all domestic waste is $48,900 for new constructions and $81,600 for conversions. The estimates were based on conceptual piping details and data from the installation of the Fairbanks-Morse unit on the USS FISKE (DD-842), a DD-710 class destroyer. These figures, however, are far lower than estimates obtained from cost data now available [Booz-Allen, 1969].

Presently, the estimated cost of placing central holding tanks on a DD-710 class destroyer varies from $410,000 to over $550,000, depending upon the source of the figures. Planning Engineering Repair and Alterations, Antisubmarine Warfare (PERA-ASW) did a study on this aspect of installation, but the figures generated were unavailable for quotation when requested.

Cost estimates were made for a soil and waste collection, holding and transfer system for the USS DIXON (AS-37). The job estimate [Puget Sound Naval Shipyard, 1971] was based upon installation of:

  a. Two receiving tanks of approximately 4,000
      gallons capacity each to collect ship drainage
      by gravity flow and to receive drainage from
      submarines along-side.

b. One large holding tank of approximately 14,000
       gallons to collect the excess from the two
       collecting tanks.

   c. Proper piping and pump installations so that
       receiving tanks can pump either to the discharge
       outlet or to the holding tank and the holding
       tank can pump only to the discharge port.

   d. Automatic/manual controlled pumps located adja-
       cent to each tank.

   e. Discharge connections and submarine receiving
       connections located at mooring stations 1, 2,
       5, and 6 on the third deck.

Based upon the work order as stated, the estimated cost
was $1,207,800 broken down as follows:

Material	$ 269,155
Labor, Production	442,695
Overhead Production	383,900
Routine Services	42,385
Design Services	69,665
	$1,207,800

B. PORTABLE TOILETS

   1. Introduction

       At the other end of the scale of shipboard holding
tanks are small, individual holding tanks, each with its
own toilet. Portable toilets, supplied and serviced by a
commercial dealer, have been used by ships in the past on
a very short-term basis. Private shipyards in San Diego
rent portable facilities when heads are inoperable on ships
in the yards. Their use could be extended to all ships that

have no other way of disposing of or treating human wastes.
The advantages of such a system all result from its temporary
and portable nature. It could be utilized without a large
initial investment for manufacture and installation, money
that would be lost in other short-term systems upon removal
to make way for more advanced systems in the future. The
system could be readily reduced as needed when future
installations are completed. Such changes would entail
abandoning material investment in virtually every other
system except such a rental. The largest advantage a
rental system has is an important one from a pollution
standpoint--time. It appears to be the only alternative
capable of being installed and operating immediately.

   2.   Description and Analysis of Portable Toilets

         The use of portable facilities to combat pollution
is in direct conflict with another area of major concern in
the Navy today. It would degrade habitability conditions a
great deal. The location of the facilities would have to
be on the pier or, at best, on deck or in a hanger area.
Personnel would thus be inconvenienced by the use of remote
facilities. Space aboard the ship and on the pier would be
lost, as would time on the job, and having no means for
washing close by is undesirable from a sanitation point of
view.

         These inconveniences could be quite disturbing to ship-
board personnel, and an intense indoctrination program would
be required with the use of portable toilet facilities.

A recent survey on personnel attitudes concluded, "The average Navy man considers it acceptable to throw small objects over the side while in port." This viewpoint and the hundreds of pounds of floating trash removed from the water each day indicates that, although pollution is disagreeable to all, pollution control often takes second place to personal expediency; however, the survey also concluded that, "A training program in the field of pollution abatement can modify attitudes." [Naval Manpower and Material Analysis Center, 1971.]

It probably would be more difficult to convince Navy personnel of the necessity for walking to the pier to use an outside toilet, especially in the middle of the night. In the past, however, personnel have responded quite favorably to the problems incurred when a new or experimental system is placed on their ship. The response to the Fairbanks-Morse unit and its associated work aboard the USS FULTON (AS-11) was excellent. Personnel generally took an enthusiastic and cooperative attitude toward the project. Destroyer Development Group also has found personnel quite receptive to the added work and problems associated with projects of this type.

One major inconcenience could be reduced considerably, that of getting up and walking to the pier in the middle of the night. During this minimum use period, small portable containers, such as camping toilets, could be located in the heads for urine. These facilities would be acceptable

on this limited basis. But other than this, habitability degradation as mentioned above is not likely to be overcome. At best, it can be minimized through convenient locations of the facilities in adequate numbers. Other than this, the problem would have to be endured for the benefit of immediate "zero" pollution by sewage.

Portable facilities would reduce sewage pollution to zero, but only while ships are tied up. Also, shower, galley, laundry, and other domestic waste would be discharged overboard. In transit, sewage would also be discharged overboard, polluting the bay. But of course, portable toilets are not for the Navy to live with indefinitely. Reduction of pollution immediately would be the goal, and a considerable reduction could be effected with this system. An analysis has been made of time in transit versus time in port for San Diego based ships [Farrell, 1972]. On time considerations alone, the percent of BOD discharged in transit was estimated to be less than five percent of the total.

The most popular use for chemical toilets now is on construction sites. Units are provided at the rate of one per ten men usually, and are serviced by the dealer once a week. Servicing includes pumping out the tank, recharging with the chemicals, and cleaning up the inside of the unit. The dealers recommend not less than one unit for twenty men, and this is also the local minimum for construction sites set by the city. Servicing more than twice a week would

allow a smaller number of units to be used. However, simply halving the number of units would require daily servicing, and the price for daily servicing ranges from more than two to three times the cost for twice-weekly servicing.

Another consideration in the number of units required is personnel needs. More than twenty people per unit would possibly cause delays and inconvenience in use. Commodes aboard Destroyer types run from one for each fourteen crew members on a DLG to one for each twenty-two on a DE. One portable for each twenty men would be a good starting point for the system, and the number could be modified up or down as necessary.

When facilities are rented for ships under construction in three private shipyards, they are located on the deck of the ships. This is more convenient than placing them on the piers, but there are two problems. The first is space. The units are three and one-half feet by four feet by eight feet tall. Two or three of these on the deck of a DD under construction for use by a few personnel take little space. But ten or fifteen, as required for Destroyer types, would take considerable deck space.

The second problem is servicing. None of the companies interviewed can service units on-board ship, or even pier-side, due to equipment limitations. When units are used now on deck, a yard crane lifts them off on the evening they are to be serviced and then puts them back aboard the next morning. This also is impractical for a large number of

units at the Destroyer piers. Portable, rented units would have to be placed on the piers.

3. <u>San Diego Naval Station Requirements</u>

To estimate the number of units required and their cost, consider just the Naval Station area of San Diego. The average number of ships at the station is 59, with about 22,000 men [Kennedy, 1969]. This is based on the actual number stationed modified by average time in port. Cost estimates were obtained from three of the largest dealers in San Diego; Casey's, Deter's and Shamrock Chemical Toilet Rentals. The prices vary depending upon the servicing frequency desired, but the average is about $30 per month for twice-a-week service. So immediate stopping of sewage discharge from ships at the Naval Station with the portable rental toilets would require 1,100 units at an estimated cost of $33,000 per month.

A second possibility for use of portable toilets is for the Navy to purchase or build the units and service them itself. The units are available from a dealer for about two hundred thirty dollars each, so 1,000 units would have an initial cost of $253,000.

The San Diego County Parks Department has purchased some portable units and has one truck for servicing them. The truck is simply a flat truck mounted with a tank and pumping system designed by the Joor Manufacturing Co. of Escondido, Ca. Two tanks hold 650 gallons of sewage and 150 gallons of fresh water for recharging the units. The system cost was $6,000.

Twenty men will produce a total effluent averaging
approximately nine gallons per day. A three-day period will
yield 32 gallons, including five gallons of water and chem-
icals originally charging the unit. This is about the
average quantity advisable before servicing is necessary.
The 650-gallon tank, then, holds effluent from twenty
units. If two trips were made per day, each truck could
service forty units per day or 120 units per week, twice a
week. Commercial trucks can service 80 units in a day, but
this is with daily servicing, so that pumping times are
shorter and the truck holds all the sewage in one trip.
Thus, about ten trucks would be required at a cost of
$60,000.

If Navy personnel were used to drive the trucks, person-
nel costs would be about $3,500 per month. The chemical
used in the units is a formaldehyde base mix. Bass Chemical
Co. of San Diego supplies these chemicals to dealers at a
cost of about fifteen cents for charging each unit. The
total monthly cost for operators and chemicals therefore is
about $5,000. The total cost for the Naval station would
thus be $313,000 initially and $5,000 per month, plus main-
tenance and gasoline for the trucks. It would thus be more
economical to buy a system of units if the use would exceed
eleven months.

C. CONCLUSIONS AND RECOMMENDATIONS

The concept of a centralized holding tank, as designed
by the Naval Ship Engineering Center, leads to extensive

interior modification of existing ship structures. If a
new ship is designed with this feature as an integral part
of the internal structure, this approach is sound. To use
this concept for existing hulls, however, leads to the
following problems:

1. Space limitations of the vessel.
2. Relocation of equipment displaced by the tank and
   its related equipment.
3. Decrease in the operational range if fuel tanks are
   converted into holding tanks.
4. High cost of installation, piping, and rerouting of
   all sanitary waste drains.

Because of these difficulties, it is concluded that a cen-
tralized holding system should not be installed on existing
vessels.

The other extreme in holding tanks--that of small,
individual tanks used with portable toilets attached--also
has many difficulties. The concept of portable pier facili-
ties is purposely crude. It is little better than backyard
outhouses. The toilets would be an eyesore on the piers,
a lot of trouble to maintain and service, and, most impor-
tantly, a burden to the officers and men who use them. But
the basic simplicity of this approach is its strongest sel-
ling point. It would require no lead time, and would reduce
BOD, SS, and coliform from participating ships to zero. The
question is whether or not the pollution concern is strong
enough and immediate enough for the system to be desirable,
given its obvious drawbacks.

An alternative to these two uses of holding tanks is a small capacity surge tank used with a transfer system for pumping waste ashore. This versatile transfer system is proposed in the following section of this chapter.

IV.   SHIPBOARD SEWAGE TRANSFER ASSEMBLY

A.   INTRODUCTION

The holding tank alternatives discussed so far are designed with large storage/holding capabilities as a major feature. The systems allocate large amounts of ship's space to collect waste when transitting restricted waters; this facet of operation is questionalbe for two reasons. The first is that on time considerations alone, the percent of BOD discharged in transit is estimated to be less than five percent of the total. This is based on analysis of time in transit versus time in port for San Diego based ships [Farrell, 1972].

Secondly, in December of 1971, a resolution was unanimously passed by the California Water Resources Board that will be recommended to the Environmental Protection Agency that standards affecting Navy ships should not apply while underway. In support of this, the members of the EPA office in San Francisco agreed that the pollution effect of underway vessels is minimal and no further research is necessary.[1]

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[1]These agreements were summarized in a Naval Undersea Research and Development Center Letter Ser. 1514-11 of 18 January 1972 to Professor C. Rowell of the Naval Postgraduate School.

With this in mind, a preliminary draft of an on-board transfer unit with only sufficient holding space to absorb any surge conditions and a capacity to insure efficient transfer pump operation was designed. The Shipboard Sewage Transfer Assembly (SSTA) was engineered to be used on existing ships where extensive interior modifications cannot be justified for either logistic or economic reasons. When compared to a massive centralized holding/transfer tank, the SSTA unit could be installed on many ships with severe space limitations as an efficient transfer mechanism for sewage to a pier or barge facility.

B. PRELIMINARY CONSIDERATIONS OF POSSIBLE CONFIGURATIONS

Several alternatives for a transfer unit were investigated by the study group and discarded for various reasons. The original outlook was oriented towards an exterior collection/transfer system to manage ships liquid wastes. An exterior unit has the following major advantages over an interior design configuration.

1. No modification of the internal ships configuration.

2. Initial cost of material and parts would be far less than the cost of the centralized holding tank system.

3. The unit could be built in a short time and be a quick answer to the sewage transfer problem.

4. All parts of the unit would be off-the-shelf items and would not require any major research and development efforts.

The following is a summary of the possible configurations studied, a brief description of the component's operation and the related merits and demerits of each.

1. External Manifolding

Two possible configurations were investigated to collect the wastewater from the ship's discharge ports by gravity alone. A permanent and portable manifold were studied.

a. Welded Manifold

A six-inch pipe, cut in half, could be welded to the side of a ship to act as a collector/channel for all sewage and waste liquids. The waste would flow out of the pipe at the stern under the force of gravity and be transferred by hoses to a collection device.

b. Flexible Hose Manifold

A quick connect/disconnect device could be fitted over each discharge port and be used to channel the waste into hoses for delivery to a receiving facility. Each port or two adjacent ports would be connected to a main feeder line to reduce the number of hoses in use.

2. Forcing Mechanisms

Realizing that gravity flow alone would be insufficient to force the sewage over long distances, a forcing mechanism was needed to act as a booster. The first two concepts rely on the ships fire and flushing main and the last one on an exterior pump.

a. Periodic Burst of Water

A periodic burst of water from either the ship's fire and flushing main or a pierside main would be used as a transport medium for the sewage. The water would act as a ram to drive the sewage through the hoses.

b. Constant Flow

Essentially the same as the preceeding except with constant flow. The high pressure water is used as an inductor to "suck" the sewage out of the feeder lines and force the wastes through the main line.

c. Floating External Pumping Platform

A system of collection tanks could be placed at or near the discharge ports to collect and periodically pump sewage and liquid waste to a barge or sewer through water-born or deck-laid hoses.

3. Possible Configurations

The preceeding manifolding and transfer components were studied by the group. Various combinations were investigated and all found to be deficient in operation and practicality. Table 3-5 is a compilation of the sub-systems studied and their related merits and demerits.

4. Additional Constraints for the Design of SSTA

The SSTA unit was designed with these points in mind as well as the drawbacks of the centralized transfer/holding concept. The disadvantages observed in the table resulted in the development of additional constraints upon the system design. They are the avoidance of:

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TABLE 3-5

Merits and Demerits of Components of Possible Configurations

	MANIFOLD		FORCING MECH.		
	1A	1B	2A	2B	2C
DEMERITS					
Vulnerability to Damage	X	X	X	X	X
Ability to Inflict Damage	X	X	X	X	X
Poor Flow in Hoses	X	X			
Poor Flow in Manifolding	X			X	X
Underwater Discharge	X				
Gravity Flow	X	X			
Blockage in Hoses	X	X	X		
Blockage in Manifold	X		X	X	X
Water Born Hoses	X	X	X	X	X
Small Craft for Installation	X	X	X	X	X
Increase in Waste Volume			X	X	
Tapping off the Firemain			X	X	
Additional Hoses	X	X	X	X	X
Backup into Ship	X	X	X		
Increased Power Demands			X	X	X
Numerous External Equipment		X		X	X
MERITS					
No Interior Modification	X	X			X
Small R&D Effort	X	X	X	X	X
Comparatively Inexpensive	X	X	X	X	X
Quick Answer to Problem	X	X	X	X	X
Off-the-Shelf Items	X	X	X	X	X

a. External connectors that penetrate the ship's hull and are vulnerable to damage from ships.

b. Small, external collecting/transfer devices.

c. Gravity for the main forcing mechanism.

d. The reduction of watertight integrity resulting from hull and bulkhead piercing.

e. Hull girder penetrations.

f. Extensive research and development for system components.

g. Bulky or heavy portable equipment.

h. Extensive maintenance requirements.

i. High installation costs.

j. Multiple designs.

k. Water-born hoses.

l. Space-consuming equipment

C. DESCRIPTION OF THE SHIPBOARD SEWAGE TRANSFER ASSEMBLY

The SSTA unit utilizes a storage tank of 200 gallons capacity, a grinder/transfer pump and a simple system of valves and piping allowing for disposal in several ways. The grinder/transfer pump will macerate the solids into $\frac{1}{4}$ - inch particles and discharge under pressure through $1\frac{1}{4}$ - inch piping to a pierside connection or to a barge. Discharge will be through appropriate connectors above the main deck. A flow diagram of the system is shown in Figure 3-1.

The tank and pump will be located beneath the head. The tank is small enough to be located so as not to eliminate
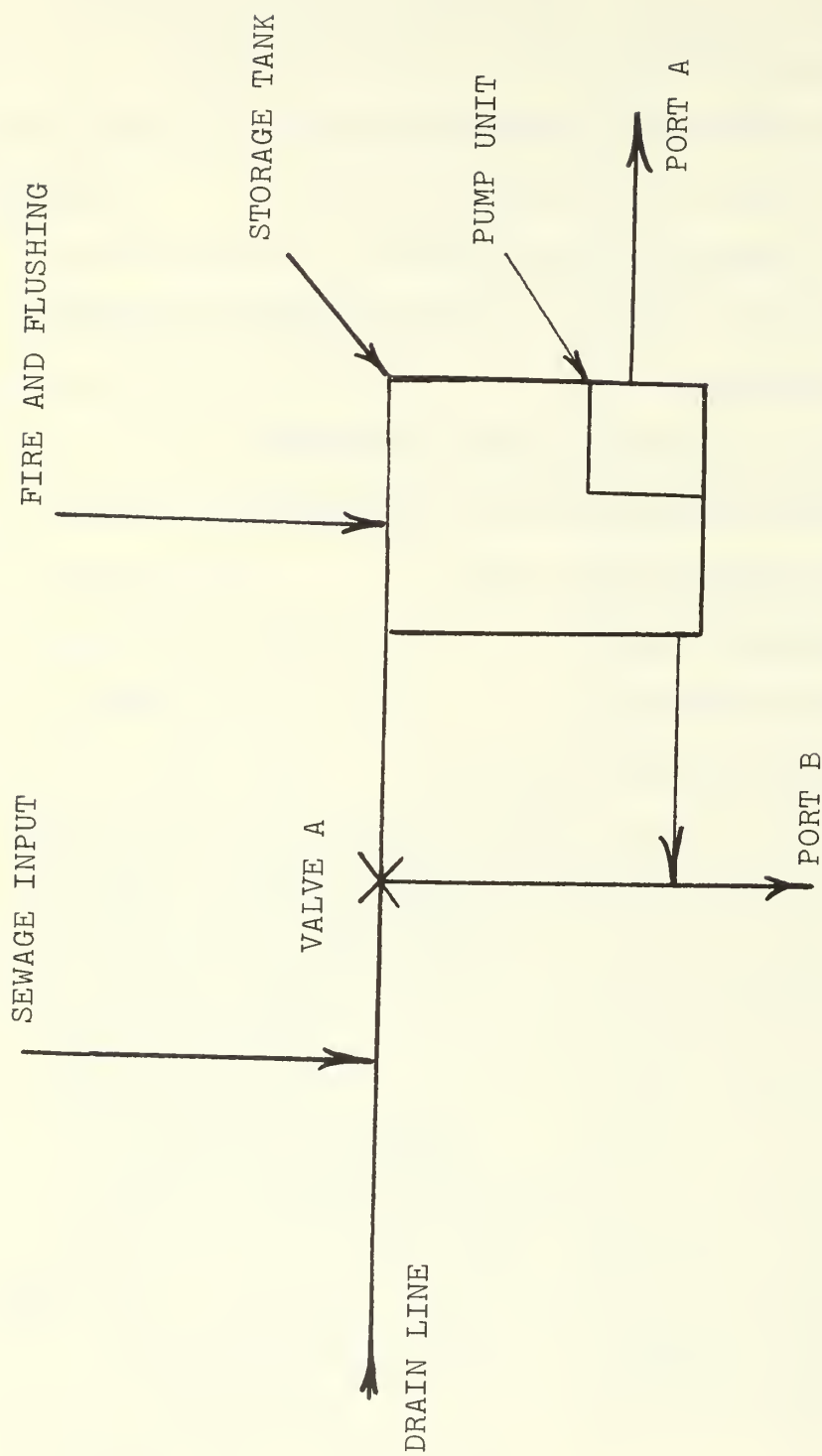
Figure 3-1. Flow Diagram of Shipboard Transfer Assembly.

equipment space and thus not detract from the ships offensive capability.

A proper highwater, or pump malfunction, alarm will be installed for safety measures, and a bypass drain will be included for overflow. The ship's fire and flushing main will serve as the cleaning agent for the system.

If the grinder/transfer pump should fail, an emergency alarm is activated. Provisions are made so that the tank can be drained overboard or pumped out by hand.

From the external fittings, the sewage will be directed into quick hook-up, rubber, light-weight hoses for eventual discharge into some receiving facility. For nested ships, hoses would be cascaded using increasing diameter hoses so that it will be necessary to extend only one or two hoses over a nest of ships. The unit has been designed to be compatible with the Kennedy Engineers Report [Kennedy, 1969]. The peak flow rates, from a nest of 5 destroyers is below the capacity of the pierside sewer system. All hoses and fittings would belong to the Naval Station and would be handled in the same manner as steam and electric cables are handled now. The SSTA unit would cause little additional obstruction to a nest operation. The unit is deliberately open-ended so that it may be designed to fit any ship and that a naval architect can use the basic idea to design safety and habitability features into each installation.

It is feasible to mount a larger pump and thereby handle larger volumes and reduce the size of the transfer tank.

It is also possible to locate the system so that it can service two separate but nearby heads (e.g.: forward crew and forward officer's head, DD-710 class destroyer). For an analysis of the design parameters and the characteristics of the integral components of the system, refer to Appendix A.

D.   OPERATION OF THE SHIPBOARD SEWAGE TRANSFER ASSEMBLY

The system will operate for sanitary transfer only. It will be used to transfer sewage from the ship to a pier or barge for either treatment or storage, or simply to macerate the waste before discharge over-board while in a foreign port.

When the ship is alongside a pier, anchored or moored in a nest, the SSTA unit is activated by setting three-way valve "A" so that the sewage is channeled into the storage tank, instead of overboard. As the tank fills, the grinder/transfer pump is activated at a distinct level and all sewage is macerated and discharged under pressure to the receiving facility. Discharge is either through the existing gravity drains (foreign port) or through the 01 deck or weather bulkheads of the main deck and into transfer hoses.

The tank is capable of being flushed; this will be done periodically so that all equipment will remain clean and blockage will not occur. The system will be vented to the gravity drain. A sink trap will be installed upstream from the tank entrance to prevent large foreign objects from getting into the tank and to make the tank air tight, except for the vent to the gravity drain.

E. SHIPBOARD SEWAGE TRANSFER ASSEMBLY UNIT
    AND INSTALLATION COST ESTIMATES

The SSTA unit is similar in design to components of the
General Electric Shipboard Waste Treatment System installed
for testing and evaluation aboard the USS KOELSCH (DE 1049).
The similarity lies in the small holding tank, the grinder/
transfer pump, the small diameter transfer lines and the
ability to discharge overboard. The major difference is
that the G.E. system is a treatment plant whereas the SSTA
unit is a transfer assembly only.

Based upon the General Electric unit installed aboard
the KOELSCH and its related cost estimates, it is estimated
that a 125-man SSTA unit, installed on a DD-710 destroyer
would cost between $6,000 and $8,500. This is broken down
as follows:

	Thousands of Dollars
Tank, Sensors, Indicators	1 - 1.5
Pump	1.0
Labor for Piping and Unit Installation	4.0-6.0
TOTAL	6.0-8.5

For a DD-710 destroyer, two, or possibly three, units
would have to be installed. For the forward head areas,
smaller units would be installed at a lesser cost. The
price of the system is strongly dependent upon piping instal-
lation. If two or three small heads are interconnected by
piping, the price per unit would be increased. Based upon
two large and one small unit being placed aboard a DD-710
class ship, the overall estimated cost would be between
$20,000 and $23,500. This is subdivided as follows:

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	Thousands of Dollars
Tank, Sensors, Indicators	3.0-4.5
Pumps	3.0
Labor for Piping and Unit Installation	14.0-16.0
TOTAL	20.0-23.5

F. CONCLUSIONS AND RECOMMENDATIONS

The Shipboard Sewage Transfer Assembly was designed to
meet the needs for an efficient transfer mechanism that would
be compatible with ships that cannot afford extensive interior
modifications. The SSTA unit, when compared to the central-
ized holding tank concept, exceeds the latter for the
following reasons:

1. The estimated cost per ship is far less than that of
    the centralized holding tank ($22,000 vs about one
    half million dollars--see Section III-A).

2. The requirement for major repiping or rerouting of
    existing drainage systems does not exist.

3. There is no requirement for major discharge piping.

4. All components are existing stock items.

5. Extensive research and development is not required.

6. Relocation of existing internal machinery is not
    required.

7. Installation of the basic unit on-board all ships,
    independent of type or class, is feasible.

8. The requirement to handle larger volumes of waste
    can be handled by simply installing a bigger pump.

9. The primary mission of the ship is not degraded.

10. The range of the ship is not limited due to recon-
figuration of existing fuel tanks.

11. The unit is a basic item for use with any future
systems installed on-board or pierside--on-board
treatment systems generally will require grinders,
transfer piping, and storage tanks for pacine
influent flow, and transfer, storage and treatment
off-ship is facilitated by grinders and piping
already installed.

The preceding merits of the SSTA with its versatility
of transfer to an on-board treatment unit, if one is sub-
sequently installed aboard ships, or discharge to ashore or
afloat receiving facilities warrant its installation aboard
Navy ships. Various alternative off-ship receiving facili-
ties are examined in the following sections.

V. EXTERNAL WASTE RECEIVING SYSTEMS

A. INTRODUCTION

The desired result of the Shipboard Sewage Transfer
Assembly described in Section IV is the ultimate transfer of
shipboard waste ashore. A piping system from the pier to
the city sewage treatment plant can be expected to be
installed at many US Navy facilities by 1980 (see Section VI
of this chapter). A containment system of some type, such
as a holding tank or barge, whether afloat or land-based,
should be considered as a possible interim measure.

B. FACTORS TO BE CONSIDERED

Afloat receiving systems have the following appealing
aspects:

1. They are temporary. Permanent constructions would
    require deep sumps or long shallow tanks, perhaps
    running the entire length of the pier. Feasibility
    of excavation and construction under some piers is
    doubtful. Once on-board treatment plants are
    common, or pierside sewers are available, permanent
    tanks would be abandoned.

2. No retrofitting of older ships is required, as would
    be the case with on-board holding tanks.

3. They are portable and can serve ships both at piers
    and anchorages. For dumping, they could either be
    taken to a pier in the immediate vicinity that
    already has the sewer system connected, or to sea
    until facilities are available on at least one
    pier ashore.

4. They could be made of truly portable containers
    stored aboard ship until used. This would allow use
    even after the major United States ports have city
    sewage systems at the piers. Thus, in foreign ports
    where facilities are not available for pumping
    ashore but the port is sensitive to overboard dis-
    charge, the tanks could be used and towed to sea
    for dumping.

5. The system can easily be expanded or contracted,
    as activity in a given port area demands. This would

not be possible with permanent external storage containers.

6. They could have the capability of processing sewage on the spot. Instead of installing treatment systems on-board vessels, resulting in expensively retrofitting older ships, an afloat system could handle their requirements. The systems would be manned by personnel well qualified to operate such treatment systems, thus relieving shipboard personnel of this task.

7. Indirectly, they would acquaint shipboard personnel with the routine for implementation of pierside piping that will be the ultimate standard system.

The important considerations are:

1. Cost--Must new vessels be built for the designated purpose or can certain existing vessels be converted? Is off-the-shelf, ancillary equipment available to support them? Is the system cost effective?

2. Size and capacities--How many ships can the tank or barge service, and how often must it be emptied? If a treatment system is utilized, what is its daily capacity?

3. Propulsion--Is it self-propelled, or must tug service be provided?

The following discussion deals with storage devices that might be used.

C.   PREFABRICATED STORAGE TANKS

   1.   Background

      Temporary storage containers for sewage and other
liquids are presently being utilized or developed in a
number of systems. Underwater Development Corp. of Washing-
ton D.C. has anchored two 100,000-gallon synthetic rubber-
coated nylon fabric tanks in the Anacostia River [Water
Pollution Control Research, December, 1969]. The tanks,
manufactured by Goodyear Tire and Rubber Co., are for
temporary storage of sewage during peak periods. During
heavy rains, the sewer system is overtaxed with storm drain
water and often overflows through runoffs into the Anacostia
River. Under the new tank system, the overflow is directed
into the underwater storage tanks for retention until a
slack period allows pumping back into the city system for
normal treatment.

      This same type of storage container was installed in a
boat marina on the Anacostia River [Water Pollution Control
Research, September, 1969]. Secured underwater, the flex-
ible tank receives waste from ten small boats in a pilot
project. The tank contents are pumped to an onshore treat-
ment plant.

      Uniroyal manufactures flexible, portable storage tanks
in sizes from 250-gallons capacity to 100,000-gallons. The
tanks are portable in the sense that they are light and
flexible, and fold up for storage and transporting. But,
like the tanks mentioned above, they are static tanks. That

is, they are designed to be fixed while in use. They could
be utilized in a system of temporary holding tanks below
a ship's berthing area, as opposed to permanently constructed
tanks, but they suffer many of the same drawbacks. Such a
system requires barges or other means of pumping out the
tank for treatment or disposal, the same as truly portable
tanks. But they cannot be moved to remote pumping stations
if necessary. When the piers obtain sewer systems, the large
holding tanks will not be required.

Uniroyal also has a storage bag system that is truly
portable in use. The bags were developed by them for the
Coast Guard. The system, ADAPTS (Air-Deliverable Anti-
Pollution Transfer System), will be used to off-load oil
from stricken tankers. The filled bag will then be towed
into port or to an empty tanker for off-loading of the oil.

2. Portable Storage Bags

The ADAPTS type bag can meet the system requirements
outlined above for portable storage tanks. During testing,
there were some ruptures in the bag. One type of failure
was at the tow point, but this weakness has been corrected
with reinforcing. A second failure occurred when the full
bag was lifted with a single line around it. Now the bags
are fitted with lifting eyes and are easily manageable.
Since the present design is for short-term emergency use in
a light, air-droppable construction, modifications may be
necessary for continuous use as sewage containers. The
rubber/nylon fabric is flexible and abrasion resistant down

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to -25 degrees F, and a double construction can give the necessary added strength.

Flexible, the bags can be folded up for transfer or storage. When in use, they can be filled by means of the Shipboard Transfer Assembly described previously, or by any other pumping system. Keeping one end raised slightly alleviates any problems with folds in the bag restricting flow. According to information supplied by the manufacturer, they can be pumped out completely with a suction pump, with no problems of bag collapse stopping suction. The containers come in a variety of sizes, four examples of which are listed in Table 3-6.

A Destroyer type ship with a complement of 300 men would discharge 9,000 gallons per day, based upon 30 gal/man/day. The 1000-bbl bag would hold waste discharge for a three-day period, allowing bi-weekly emptying at a pier connection or at sea. Two containers could float at the stern of two

TABLE 3-6

Portable Storage Bag Characteristics

SIZE	CAPACITY (gal)	DIMENSIONS (ft)
500 bbl	15,750	60.6 x 10.1 x 6
1000 bbl	31,500	76.5 x 2.8
2000 bbl	63,000	96.1 x 16.0
3000 bbl	94,500	110.1 x 18

nested DD's, athwartships. This would allow easy access for towing hook-up. It would also minimize the moving of the containers for breasting out ships in the nest to get one underway, which would present a problem if the bags were between ships. This arrangement would also minimize ship action against the bags from weather. If abrasive wave action were found to be a problem in prototypes, protective shells could easily be constructed for each bag. Made in a skeletal cylindrical shape with sealed pipes, the shell would float around the bag to protect it from abrasions. Openings at either end allow the container to slide in and out.

3. Underline San Diego Application

Various sizes of ships require different sizes of containers, a different number of containers per ship, or a different schedule for emptying. Implementation would be easier if all containers handled were the same size. To get a cost estimate for the San Diego Naval Station, assume that only 1,000-bbl bags are used, and that they are emptied twice a week. One device for each 300 men requires 74 bags at the Naval Station, at an initial cost of about $1,410,800.

Using larger containers would increase problems with storage and handling, but would significantly cut the cost of procurement. Assuming the same schedule of emptying, so that the same total storage capacity is required, only 25 of the 3,000-bbl bags are needed, at a cost of $765,000. The cost per gallon of storage with the larger size is about 32 cents, while with the 1,000-bbl bag it is about 61 cents.

Some of the reasons for considering portable temporary storage containers over permanent ones have already been cited. Even so, it may be interesting to compare the cost of obtaining portable devices with the cost of constructing permanent underwater storage tanks. Underwater storage of about the same capacity (two million gallons) in the Anacostia River project was estimated to have a construction cost of 28.2 cents per gallon overall and 16.9 cents per gallon for the storage tanks alone. So to obtain the advantages of small, portable containers over large ones permanently installed, an increase in cost per gallon must be paid.

D. CRAFT FOR EXTERNAL STORAGE OR TREATMENT OF WASTEWATER

1. Scavenger Barges

There are several examples of collection and barging operations that have been carried out successfully. Refuse and garbage originating from Naval and commercial vessels in San Diego are transported 20 miles from the coast in various versions of the U.S. Navy's YG class scows. Load capacity varies between 25 and 136 tons [Marbil, 1966]. At present, one ship per week is the average. Cannery wastes are deposited at sea for the San Francisco area from June to October each year. The wastes are taken to sea aboard a 1000-ton barge under tow. The cost for bulk industrial waste is on the average $1.00/ton on the Pacific coast and $1.80/ton on the Atlantic coast, and the cost for refuse and garbage is $15.00/ton. The cost for sewage sludge is on the average $1.00/ton [Smith, 1971].

About one-half of the total tonnage of sewage sludge disposed of at sea from the New York area is handled by a fleet of five self-propelled barges operated by the city of New York at an annual cost of $1,250,000. These barges have capacities of between 1,200 and 3,200 tons. In addition, a 6,000-ton capacity barge is employed by the New York-New Jersey area [Smith, 1971].

In contrast to the large scale sludge disposal operations from New York City, sewage sludge for Philadelphia is handled by a single converted tank barge having a capacity of 2,000 tons at an annual cost of $336,000 [Smith, 1971]. About 150 trips are made annually to a dumping area located 227 miles from the coast.

2. Preliminary Considerations in Selecting a Barge

In pursuing a design analysis of storage vessels, an understanding of loading capabilities must be obtained. This analysis is based on the collection of human waste only. Thus, the discharge rate used will be understood to be 30 gal/man/day. A gallon of wastewater weighs about 8.6 pounds. Consequently, 30 gal/man/day is equivalent to 258 pounds or 0.116 long tons of wastewater per man per day.

Assuming that 70 percent of a ship's crew is on-board during a day [Booz-Allen, 1969] results in Table 3-7 for daily discharge quantities.

These results will be used to indicate loading requirements for devices used either as storage units or afloat treatment systems.

TABLE 3-7

Anticipated Daily Sewage Discharge
for Selected Ship Types

SHIP TYPE	COMPLEMENT	DISCHARGE RATE (gal/day) (70% complement)	SEWAGE WEIGHT (long tons)
AO 22	290	6,100	23.6
AOE 1	598	12,550	48.5
AD 14	1,131	23,800	92.2
CG 10	1,262	25,500	101.5
CVA 59	3,826	80,500	311.0
DE 1006	206	4,330	16.8
DD 710	296	6,230	24.0
MSO 421	74	1,555	6.0
SS	81	1,703	6.6
SSN/SSBN	124	2,600	10.1

In the analysis that follows, two loading situations
will be considered. The first is a nest of five DD-710 class
destroyers moored at a pier, and the second is a fast attack
carrier, CVA-59, either at anchor, or moored pierside.

3. Yard Craft

The following storage devices, designated yard craft,
are located at most Naval Stations to provide services such
as water replenishment, sludge removal, and oil and gasoline
refueling. Table 3-8 lists them, along with their capaci-
ties and dimensions.

All craft have transfer pumps on board to discharge
their contents. Analyzing the storage capabilities of a
self-propelled YO indicates a storage capability for 7-8
days for a nest of five Destroyers, or a three-day capa-
bility to service a CVA. Table 3-9 compares the capabili-
ties for the various service craft.

TABLE 3-8

Yard Service Craft

NAME	DESIGNATION	STORAGE CAPACITY[2] (long tons)	EXTERNAL DIMENSIONS (ft)
Fuel Oil Barge*	YO	1000	16x35x8
Gasoline Barge*	YOG	1830	16x35x8
Gasoline Barge**	YOGN	1830	16x35x8
Fuel Oil Barge**	YON	1495	16x35x8
Sludge Removal Barge	YSR	195	95x35x7
Water Barge*	YW	1000	16x35x8
Water Barge**	YWN	1000	16x35x8

*Self Propelled
**Non-self Propelled

TABLE 3-9

Anticipated Service Craft Capabilities

CRAFT	FIVE-DESTROYER NEST (days)	ONE CVA (days)
YO	7-8	3
YOG	14	5
YOGN	14	5
YON	11-12	4.5
YSR	1.5	0.6
YW	7-8	3
YWN	7-8	3

[2]Figures were provided by Yard Service Operations Office, Hunter's Point Naval Shipyard, San Francisco.

If such vessels were considered for use, transfer pumps and piping would require that some type of cathodic protection be provided and that tanks be coated with a resin base spray to inhibit the corrosive effects from anaerobic decomposition that might occur. The tanks would have to be vented properly, as well as deodorized. Self-propelled service craft are highly maneuverable, whereas non-self-propelled craft are designed for use with tugs or other yard craft.

4. Utility Landing Craft (LCU)

Utility Landing Craft (LCU) have been built to assist in carrying heavy artillery ashore during amphibious operations. Their normal load varies from three to six tanks. The three classes of this craft are compared in Table 3-10. Although the LCU 1610 series and 1466 series are seldom used for such operations, the older 501 series is utilized at many bases as a general cargo craft and as a yard service craft accomplishing jobs normally done by yard tugs.

TABLE 3-10

Utility Landing Craft

CLASS	NUMBER IN CLASS	YEARS BUILT	DISPLACEMENT (long tons) LIGHT	FULL	DIMENSIONS (ft)
501	26	1943–1945	143–160	309–320	119x32.7x5
1466	42	1950–1955	180	360	119x34x6
1610	26	1966–1968	200	375	135x29x5.5

All landing craft are built with high maneuverability, being able to move laterally as well as longitudinally. The two older classes have three shafts, whereas the last class is fitted with right-angle-drive propulsion units providing thrust in any direction.

A self-propelled storage barge could be configured from the oldest class of LCU's. The well deck could be completely sealed with a resin base coating to inhibit corrosion, and transfer pumps could be located in the well deck (sump) for use in discharging the contents to a disposal area. The well is configured to hold approximately 160 to 180 tons, which is enough for one day's discharge from a nest of five Destroyers or one-half the daily discharge from a CVA. Such vessels could be relieved on station by back-ups and proceed to the discharge area, or transfer of the contents could be rendered to another barge which makes several trips daily, thus allowing the hookups to remain intact.

5. Paid Services

A third approach to the collection system described previously is that of contracting scavenger barge service. This type of service would encourage participation by private enterprise, thereby perhaps reducing the cost to the individual port operation in time and expense. Fees would be based on the contractor's costs for barge construction, operation, and amount disposed of. Thus, for example, using the information on costs for the barging of sewage sludge at $1.00/ton, one can determine the annual cost for

an area. Thus, for an average of 26,000 persons serving on various vessels in San Diego, the cost for a year would be $1,080,000, assuming the cost of barging sewage waste would be the same as that for sludge. The cost for various Naval Bases is shown in Table 3-11.

TABLE 3-11

Yearly Estimated Service Costs

PORT	1971 AVERAGE SHIPBOARD PERSONNEL	ANNUAL COST
Charleston	3200	$134,000
Long Beach	8600	$361,000
Mayport	8600	$361,000
New London	1200	$500,000
Newport	8000	$335,000
Pearl Harbor	4100	$171,000
San Diego	26000	$1,080,000

6. Portable Sewage Treatment System

Certain activities are located in areas where access to open waters cannot be accomplished easily or economically, due to channel traffic or weather conditions and pierside connections are not available. This would make the "collection only" approach inapplicable. In such situations, an on-board treatment unit mounted on a barge may be feasible.

Barge-configured treatment systems would be mobile and would be operated and maintained by experienced technicians, thus relieving shipboard personnel of this task in port. The treatment system would operate on a separate power supply. Since back-up systems would not be feasible on-board

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ships, back-up barges as well as storage barges could fill
in temporarily in case of a malfunction.

Several systems embodying this philosophy are presented
in the following. Some systems are still in the planning
stages, and others are operational or are in evaluation
phases.

a.   YFN-1249

The Submarine Base in New London has received a
sewage treatment barge to evaluate the feasibility of handling
sewage from submarines (both nuclear and diesel) berthed
along piers at the base. NAVSHIPSYSCOM Code 427 conceived
the scheme for using the barge-mounted treatment systems in
September, 1970 while investigating and developing alterna-
tive systems to be considered as a back-up for the USS FULTON
(AS-11) in the event of the failure of the experimental
Fairbanks-Morse 500-man unit [Piersall, 1971]. The YFN-1249
is a non-self-propelled, covered lighter equipped with two
different bacteriological systems, a 10,000-gallon holding
tank and auxiliary power generating equipment. The treat-
ment systems were procured and installed by the Boston Naval
Shipyard.

The YFN-1249 will be used initially to process sewage
from submarines; however, any ship or craft with a single
overboard discharge line for sewage drains could be
serviced by the barge. Unlike surface craft, nuclear sub-
marines have four holding tanks for sewage. Periodically
these tanks are discharged to sea using 700-psi compressed

air. In port, discharge lines are connected from the sub-
marines to the barge. At present, connections to the
submarines are made by divers since the discharge port is
located below the waterline of the submarine (to be modified
topside by a proposed shipalt). The 10,000-gallon holding
tank is provided with two piping manifolds, port and star-
board, with provisions for four hose connections at each
manifold. The barge is equipped to provide its own
electrical power as well as having a shore power connection.

Two self-contained sewage treatment plants are installed
--a 6000-gal/day Pall Trinity Micro Model MPT 6000 and a
6000-gal/day Aquanox Inc. Model Mariner 50. In general,
the Pall Trinity unit is a bio-digestion processing device,
which incorporates the natural sewage reduction process,
accelerated through optimization of controllable parameters
(temperature and pressure). The unit weighs 18 tons,
occupies 1300 cubic feet, and costs approximately $22,000.
The Aquanox unit incorporates a mechanically-induced rapid
oxidation process with a bio-chemical reduction process to
reduce sewage. The unit weighs three tons, occupies 294
cubic feet, and costs about $4,000.

The installation cost for YFN 1249 was estimated at
$500,000, but the actual cost has been reported as being
approximately $675,000. This does not include the cost of
the barge. The sewage treatment plants are designed to
operate automatically with periodic checks. The system has
not yet been evaluated, although scheduled tests were to

be in December, 1971. At present, it is expected that the barge will be manned by civilian personnel indicating an estimated cost of $80,000 to $90,000 for the first year. For qualified enlisted operators, the estimated cost would be $62,260. Material costs are estimated at $2,000 per year [Piersall, 1971].

This is a small system under evaluation and is adequate to handle submarine sewage. It could handle two DE's with both plants in operation. Eight such barges would be required for a CVA.

b. YFNB-43

FMC Corporation, Ordance Engineering Division, has demonstrated a pilot plant on YFNB-43, a support vessel for the MK 1 Deep Diving System at Norfolk. Its plant is a physical-chemical system that treats macerated human and kitchen wastes in a holding tank with chemical additives for a short period, then processes the mixture through filters. The unit is 80 cubic feet, weighs 900 pounds, and costs $27,000. It has a processing capacity of 3000 gallons per day. Based on test results, the Navy has requested that FMC provide (on a no cost basis) a preproduction unit for test and evaluation at San Jose, California in early March, 1972. It will have a processing capability of 4300 gallons per day and cost $31,000.

c. Lockheed "E" Ship Concept

Early in 1971, the Lockheed Shipbuilding and Construction Company proposed a sewage treatment plant, housed

in surplus ship hulls to provide initial and supplementary service to cities requiring secondary treatment. In its study, the company proposed that the use of an EC 2-S-CL Liberty Ship hull could house a treatment plant to serve 50,000 people. Although this is one design, Lockheed has developed five basic systems that can be incorporated in three designs-surplus tankers or freighters, barges, or independent modular units.

The shipboard plant could be delivered to any spot in the world where at least 11 feet of draft is available. An exchange plant could be provided during overhaul; and the ships would have a life of about 30 years. Unlike individual barges, one vessel could serve an entire base. This can be visualized for ports where municipalities will not accept a saltwater flush. Flow-through pierside hook-ups could be directed to a centrally located vessel. Lockheed has not yet constructed an operating vessel, but asserts that saltwater influent could be accepted into the ship's system without difficulty. The ships are custom tailored. Lockheed's expected annual costs for operation and maintenance of the plant are estimated at $3,000,000 for servicing a population of 30,000.

        d.   INSTA Concept

            Another system that looks interesting is the INSTA barge. Diversified Technology, Inc. (DTI), a non-profit corporation located in San Diego, has proposed a barge system that would be mobile and could process sewage

as well as oily waste from bilges. The Interim Naval Sewage Treatment Assembly (INSTA) is the name given to the system, which is a self-contained barge-mounted processing unit containing a macerator, centrifuge, oil filter and separator, ultra filters, an ultraviolet scrubber, an incinerator, and an air scrubber. The company contends that the barge can be constructed from off-the-shelf items, with the exception of the incinerator. The barge would be powered by a 50-hp electric drive propulsion unit and a 75-hp diesel generator and would have centralized control and living space aboard. The company speculates on being able to service ten DD's or one CVA. It hopes to receive an EPA grant this year to develop a 5,000-gallon/day unit, planning a 50,000-gallon/day unit if successful. The company anticipates leasing their services after construction, rather than the selling of the barge.

The design is conceptual only. The company is inexperienced in the field of sanitation engineering and has not looked into the problems of ship connections, maneuverability, cost, and problems associated with incineration of wastes.

e. Trailer-Mounted Plants

Portable treatment plants mounted on trailers may serve the same purpose as the Lockheed "E" ship. Two such systems are in operation. Environment/One Corp., through its Measurement Services Division in Schenectady, New York, has constructed two mobile pilot plants in 45-foot-long highway trailers, completely enclosed and staffed with

operating personnel. One of its basic features is a complete secondary treatment system using activated sludge.

The second system, developed by Dorr Oliver of Stanford, Conn., uses an activated sludge ultrafiltration process in which sewage is filtered through a membrane at low pressure. This system was tested in 1970 at Pikes Peak. It is capable of treating up to 15,000 gallons/day. The Federal Water Quality Administration is funding development of this system to determine whether the system could provide an acceptable and economical means of sewage treatment for resort areas, mining communities, and other operations [American City, 1971].

7. San Diego Application

There are an average of 59 ships berthed daily at the San Diego Naval Station, with a total complement of close to 22,000 men, resulting in an average daily discharge of waste (30 gal/man/day) of about 66,000 gallons or 2520 long tons. Planned peak berthing is distributed as follows: nine DD's and three DE's each at piers one and two; two LPH's, two DD's, one AD, and one AOE each at piers three through eight (exclusive of seven); a total of 18 DD's at the quay walls; and nine DE's and a hotel type ship at the mole and mole pier [Kennedy, 1969].

Kennedy Engineers lists the above as the planned peak berthing, although the total peak at the station is given as 87 ships (and three barges). Assuming 87 as the peak, and assuming the two-thirds ratio of average to peak at the

station also applies roughly to individual piers, the total discharge for a three-day period averages 754 tons each at piers one and two, 772 tons at piers three through eight (exclusive of seven), 1220 tons total at the quay walls, and 428 tons at the mole pier. Using these estimates, the required number of craft for each pier was determined as shown in Table 3-12. The table shows the number of craft required if that craft were used exclusively throughout the Naval Station.

E. CONCLUSIONS

As indicated in the above table, the number required makes barge-mounted treatment systems for a single major activity like San Diego Naval Station unfeasible. A mounted unit's capacity is based upon daily processing rates. Neither the mounting of several units on-board a single barge, nor the placing of units on the pier will reduce the numbers required. This applies also to trailer mounted units.

The problem of numbers required for the LCU-configured barge is the same as above. Too many are required for each pier. In addition, there are only 26 vessels of the old 501 series in commission. The other classes were constructed more recently and are the essential support units for the amphibious branch of the Navy.

The Lockheed "E" ship would be effective since it would service the entire pier system. The concept would, however, require pierside piping and transfer systems to direct waste-

Table 3-12.   Craft for External Storage or Treatment

General	Method	Individual Cost (Prototype or Conversion Costs)	Capacity Long Tons/Unit	"Comments"	Number Required to Service 1 Pier at Naval Station San Diego (3-Day Capacity)	Total Required Piers (1-6, 8)	Number Required for Quay Walls and Mole Pier (3-Day Capacity)	Total Required for San Diego Naval Station	Remarks
Storage Only	YO	unknown	1000	require conversion	1	7	3	10	
	YOG	unknown	1830	require conversion	1	7	3	10	
	YOGN	unknown	1830	require conversion	1	7	3	10	
	YON	unknown	1495	require conversion	1	7	3	10	
	YW	unknown	1000	require conversion	1	7	3	10	
	YWN	unknown	1000	require conversion	1	7	3	10	
	LCU	unknown	160	require conversion	5	35	11	46	
	Paid Services	Determined by Contractor	Determined by Contractor						Annual cost $1,080,000
Portable Sewage Treatment	YFN (1249 Aquanox Unit)	$500,000	23.0*	Prototype at New London	12	84	27	111	*Daily Capability
	YFNB 43 (FMC Unit)	$27,000	11.4**	Prototype at Norfolk	23	161	73	234	**No Storage daily processing rate
	Lockheed 'E' Ship			Customed built				1	$3,000,000 for 30,000 population
	INSTA	$200,000	19	Concept only	14	98	69	167	
	Mobile Units	unknown	57.2	Prototype at Pike's Peak, Col.	5	35	15	50	

water to the "E" ship, as would be required for a municipal
system hook up.

The number of storage barges required indicates that
this system is the most feasible means of disposal using
water-born craft. Collection barges, whether originally
designed as such or converted from existing yard craft,
require little maintenance. They are rugged and easy to
maneuver and can be fitted with currently available pumps
for transfer and discharge.

VI. PIERSIDE SEWER SYSTEM

A. INTRODUCTION

United States Senate Bill S. 2770 makes the discharge of
any pollutant by any person unlawful, calling for complete
elimination of the discharge of pollutants by 1 January 1981.
This bill was passed by the Senate on 2 November, 1971, but
it is not yet law. Also, it contains broad provisions for
non-compliance, even for such things as cost/benefit con-
siderations. But the attitude is clear--the goal is zero
pollution.

Such requirements lead to another possible solution--
pierside connections to the city sewer system. A program is
now underway to provide facilities in various ports so that
24 large class ships can discharge all sanitary, household,
and industrial wastes into the city sewer system [CNO msg,
1971]. Factors considered have been the effects of saltwater

flush on a basically fresh water treatment system, the acceptance of saltwater flush into a municipal system by municipal authorities, the loading effects on the system, and the cost and feasibility of satisfactory performance of such a system.

B. EFFECT OF SALTWATER ON TREATMENT PROCESSES

In order to pursue current planning to transfer ships' sewage with a high saltwater content ashore, the following conclusions are given in studies made of saltwater interaction on municipal treatment plants [NAVFAC, 1969]:

"1. The basic feasibility of using aerobic biological treatment processes (activated sludge and trickling filters) for treating ship sewage flows under conditions of either constant or variable saltwater concentrations has been proven.

2. Temporary reduction in treatment efficiency can occur with abnormally severe changes in saltwater concentration when combined with unusually heavy hydraulic and organic loadings. The length of recovery will depend on the duration and severity of the unusual saltwater and plant loading condition.

3. When the plant receives normal hydraulic and organic loadings, the treatment plant effluent quality will not be significantly impaired even with severe changes of saltwater concentration in the wastewater to be treated.

4. Low hydraulic and biological loadings and high solids concentrations in the treatment units increase the tolerance of the activated sludge process to chloride changes and high chloride concentrations.

5. Extreme variations in chloride concentrations do tend to disrupt the settling rate of activated sludge. It is necessary to design secondary sedimentation units at a lower than normal hydraulic loading rate and surface skimming should be provided.

6. Anaerobic digesters are more sensitive to chlorides than those using the aerobic biological processes.

7. Chloride effects on digestion are greater as organic loading rates increase.

8. Biota in aerobic digesters require more time to adapt to chloride changes and do not recover as completely as the activated sludge process does with similar changes.

9. Aerobic digestion is likely to be more effective than anaerobic digestion for waste sludge treatment when high or variable saltwater concentrations are experienced."

Operating experience at treatment plants in Miami, Hollywood, Fort Lauderdale, and Hallendale, Florida has included influent with chloride concentrations up to 6000 mg/l in wastewater due to saltwater infiltration into sewer lines. No detrimental effects have been observed. Two extended aeration type plants in the Virgin Islands are operating successfully, treating wastewater from a saltwater flushing system. One plant is on St. Thomas Island, and the other is at Caneel Bay Plantation on St. John Island.

There should be few problems with aerobic biological treatment processes where chloride concentrations approach that of seawater. Anaerobic digesters should not present problems when chloride concentrations are below 8,000 mg/l. Chloride concentrations above 8,000 mg/l will probably cause a temporary decrease in the digester treatment efficiency of freshwater systems [Stewart, 1962; Ludzack, 1965].

C. EFFECTS OF SALTWATER ON MATERIALS

Sea or brackish water flush systems introduce a carriage liquid that has a higher conductivity and sulfate content than normal freshwater flushing systems. The two principal areas of concern associated with the use of saltwater carriage are galvanic corrosion of ferrous metals and the possible increased attack on concrete by sulfuric acid.

1. Galvanic Corrosion

Increased electrolyte concentration due to the introduction of saltwater will certainly increase the likelihood of galvanic corrosion. Published reports [Brooks, 1968; Stephens, 1957] from various industries which utilize saline waters for cooling and other processes indicate that corrosion of pumps, valves, and pipes was experienced in areas where galvanic action occurred and where cathodic protection was not provided. The municipal sewage treatment facility of Hollywood, Florida receives sewage containing approximately 1,200 mg/l chlorides as a result of saltwater infiltration into the sewers. Corrosion of comminuting devices has required the annual replacement of cutting equipment. Rebuilding of clarifiers has been necessary after five years of service and the submerged clarifier equipment requires sandblasting and painting biannually. Recent application of protective coatings has greatly reduced these problems, however [Stephens, 1957].

2. Sulfuric Acid Attack

Under anaerobic conditions, sulfates are converted to hydrogen sulfide gas which can be converted to sulfuric acid by bacterial action. This usually occurs on the moist, exposed interior surfaces of sewer pipes [NAVFAC, 1969]. The sulfuric acid attacks unprotected concrete piping. This problem has been rectified with the introduction of vitrified clay pipes and resistive linings and coatings. There is a difference of opinion among authorities as to

whether or not excess sulfate concentrations introduced by saltwater carriage results in additional production of hydrogen sulfide in sewers. It was concluded by NAVFAC [NAVFAC, 1969] that sulfates in normal wastes produce a much greater effect than those from the introduction of saltwater.

D. MUNICIPAL AUTHORITY ACCEPTANCE OF SALTWATER SEWAGE

Naval Facilities Engineering Command polled 19 continental areas to determine whether saltwater flushed sewage would be acceptable in their treatment systems. Replies vary from simple oral agreement to written contract. Boston, Newport, Philadelphia, Washington, D.C., Seattle, San Francisco, Vallejo, Los Angeles, and Honolulu have orally expressed a willingness to accept. San Diego has expressed written approval, and New London already has signed a contract to accept wastes from the USS FULTON (AS-11). No response has as yet been received from Groton, New Haven, Hampton Roads, Portsmouth, Charleston, and Key West. Bremerton is non-committal at this time [NAVFAC ltr, 1971]. Not one area responded that saltwater carriage was unacceptable. Several cities have reservations since reclamation plants are proposed and it is felt that the mineral content of saltwater would be detrimental to reprocessing. Where water reclaimed is to be used for irrigation, it is believed that it is economically prohibitive to remove the undesirable constituents introduced by saltwater which would have effects on soil and plant life.

E. PIERSIDE CONNECTIONS IN OPERATION

At present there are two systems that are in operation. In Long Beach, the hospital ship Repose is using a freshwater flush system connected to the city main. Since the ship is essentially a permanent installation, it is probably unrealistic to evaluate, but the concept of manifolding the overboard discharges and using a pump-holding tank has been applied.

The USS FULTON (AS-11) in New London has been the test bed for three subsystems. The first is the "Fairbanks-Morse Treatment System," and the second is the "Internal Manifold System," which collects all shipboard waste, including sewage and galley, laundry, and medical wastes and transfers it to a treatment plant ashore. The third, the "Submarines Alongside system," consists of one 14,000-gallon holding tank, two sewage pumps, a tank and collection piping washdown system, connections for receiving effluent from submarines alongside, and accompanying piping, valves, and hoses necessary to transfer the effluent ashore for processing. The estimated cost for the last two systems is $110,000 and $40,000 respectively [Piersall, 1971]. The ship-to-shore systems have been in operation continuously since 7 December, 1971. The Navy Department pays the city of New London $15,000 annually [United Press International, 1971] to process the FULTON's sewage in the municipal sewer system.

F. COST ESTIMATES FOR PIERSIDE CONNECTIONS

In 1968 the Naval Facilities Engineering Command author-
ized Kennedy Engineers and Reynolds, Smith, and Hills,
Architects-Engineers-Planners to provide an engineering
investigation of sewage transfer from Naval vessels to shore
facilities on the West Coast/Pacific areas and the East
Coast areas respectively. The intent of the investigation
was to provide definitive information on required facilities
and costs of collection, treatment, and disposal in an
aceptable manner of sanitary waste discharged from ships.

The study was based on an estimated flow rate by Booz-
Allen Applied Research, Inc. of 30 gal/man/day. The study
included construction and annual costs associated with the
pierside collection and treatment of ship's sewage and
involved determination of available sewer capacities,
requirements for additional lines, requirements for lift
or booster stations, requirements for sewer chlorinators
and a study into pier-mounted treatment units.

The concept of the proposed disposal system assumes
that upon entry into coastal waters the wastewater is
retained in a holding tank until the ship reaches the pier,
whereupon connection would be made to the pierside collec-
tion system and the ship would pump its waste ashore. Pump-
ing of sewage waste from nested ships is to be into the
holding tank of the next ship inboard, thereby reducing
cumulative pumping rates since minimum lines are provided
on the piers. The collecting lines along the face of the

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pier would be spaced at intervals of about 150 to 200 feet, and would utilize gravity flow.

The ship's connection would be a flush quick coupling hose connection. It would be located in a box flush with the pier. All connections, laterals, and collecting sewers on the piers or wharves would be located underneath the pier so that normal pierside operations would not be restricted. Pumping stations would be located at ends of piers where necessary to transfer sewage from secondary lines to feeder lines of municipal systems.

Examples of estimated costs are reproduced in Table 3-12 for several West Coast facilities, as compiled by Kennedy Engineers in 1969. Installation, maintenance, and treatment costs given are based on a 30 gal/man/day flow rate, and only reflect additional costs and not present operating - costs for existent systems. The cost for capital facilities for handling all domestic wastes (hotel - 60 gal/man/day) is estimated by Kennedy Engineers to be ten percent more than that for sewage alone [Kennedy, 1969].

C. CONCLUSIONS AND RECOMMENDATIONS

The pierside sewer system will soon accept waste from many large ships without extensive conversion of the vessels, and no effluent will be discharged overboard from these ships, as is necessary with most on-board treatment systems. The pierside sewer connection approach will not be affected by changing standards of effluent quality required for inport discharge. The installation cost of $2,394,000 and

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TABLE 3-13

Pier Sewer Costs for Selected West Coast Facilities

| ACTIVITY | COST FOR SEWAGE ALONE (30 gal/man/day) | | | COST FOR HOTEL WASTES (60gal/man/day) |
	TOTAL INSTALLATION	ANNUAL MAINTENANCE	ANNUAL TREATMENT	TOTAL INSTALLATION
San Diego Naval Station	$2,394,000	$18,300	$39,300	$2,633,400
Los Angeles	$3,081,600	$36,000	$38,400	$3,389,700
San Francisco	$3,857,300	$21,800	$16,100	$4,243,000
Puget Sound	$2,380,700	$24,300	$ 8,800	$2,618,700
Kodiak	$1,154,200	$ 5,500	$ 300	$1,269,600
Pearl Harbor	$3,397,000	$31,400	$23,100	$3,736,700

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maintenance and treatment cost of $57,600 per year to service the average of 59 ships at the San Diego Naval Station giving a cost per ship of about $40,500 and $1,000 respectively, compares very favorably with prices quoted previously for treatment plants: $70,000 for the installation of a single 150-man unit on the USS KOELSCH (DE-1049), and $2,200,000 installation and $202,000 annual maintenance cost for the three Fairbanks-Morse units on the USS FULTON (AS-11).

With a simple transfer system such as described in Section IV, the sewer system can be expanded to smaller ships with more active operations. Plans should be made to include all major piers in the sewer system. In the meantime, provision should be made in present installations for a central receiving station where barges or portable containers can be brought and emptied.

VII. CONCLUSIONS

The concepts of on-board treatment plants and holding tanks should be re-evaluated. Treatment at sea to reduce open ocean discharge is the only major advantage of on-board treatment plants.

The Fairbanks-Morse project should be terminated. And, before another commitment to a system is made, all facets of on-board treatment plants in general and the given system in particular should be more carefully scrutinized.

If discharge at sea and the small amount of discharge in transit is acceptable, all waste can be transferred off-ship for processing and/or disposal, where changing standards of discharge won't affect the ships' equipment. The swiftest and the most inconvenient method of sewage pollution abatement is to stop using the ships' heads when the ships are in port, and use portable toilets on the pier. The many difficulties with portable toilets outlined would have to be sustained if an immediate "zero" pollution with sewage is desired.

A system like the Shipboard Sewage Transfer Assembly should be developed and installed on ships to carry waste off. The ultimate receiving facility should be pierside sewers for all ships, and plans for sewers should be made with this in mind. Until this is possible, proto-types of a barge and of portable containers should be developed and tested so that one can be used with the transfer system when it is ready. These collection devices could continue to be used for ships at anchor or in foreign ports, where necessary, even after pierside sewers are commonplace in US Navy homeports.

VIII. <u>ACKNOWLEDGMENTS</u>

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CHAPTER FOUR

TOXICITY AND SPREADING OF OIL IN SEA WATER

LT Robert F. Barry

Abstract: The effects of bilge and ballast effluents on open ocean oil pollution are examined and it is concluded that the effect of discharging at present levels is negligible. Extensive modifications to treat bilge and ballast effluents on board ships are not necessary. Bilge and ballast discharges in confined waters can be harmful to the environment. Taking the entire inport bilge and ballast load ashore is therefore recommended. Spreading rates for inport oil spills are investigated. Retention boom criteria are presented and guidelines are established for local containment plans.

I. INTRODUCTION

No single method of abating oil pollution will apply in all cases. The problem of dealing with minute discharges in the open ocean is radically different from that of a large spill in a confined harbor area. The problem must be viewed in perspective since extensive oil pollution measures can degrade watertight integrity, reduce weight and space available for fuel or weapons systems, and drain off critically needed funds. Consequently, open ocean discharges will be treated separately from in-port discharges.

II. BILGE AND BALLAST DISCHARGES ON THE OPEN OCEAN

Bilge and ballast discharges on the open ocean are treated in this section. The open ocean is conventionally described as being over fifty miles from land. The natural processes that rapidly degrade this form of effluent are discussed. Mechanical oil-water separators are shown to be unnecessary to protect the environment from bilge and ballast effluents. Large spills are not considered because they generally do not occur from Naval vessels. If a large spill does occur, the Navy can call on the Coast Guard for assistance. The Coast Guard is actively engaged in developing the equipment and expertise to contain large open ocean spills.

A. BACKGROUND

At the Brussel's NATO meeting in 1970, the United States took the initiative and achieved wide international support for terminating all intentional discharges of oil and oily wastes from ships into the ocean by 1970, if possible, and by no later than the end of the decade [Biglane and Wyer, 1971]. The Navy will be required to completely revise bilge and ballast pumping procedures to achieve this end. Extensive modification to current ships will be required. Bilges, for example, will require an oil-water separator that removes sufficient oil from sea water to allow only a "safe" amount of oil to be discharged with the sea water. The separated oil will then be pumped to a holding tank.

The holding tank will be discharged periodically either to a shore facility or to a reception ship, perhaps a Fleet Oiler (AO). Before committing funds to such an extensive project, a thorough examination of the behavior of bilge and ballast effluents from Navy oils in the open ocean environment is necessary.

B. DESCRIPTION OF BILGE AND BALLAST EFFLUENTS

   1. Oil Types

      What oils are found in bilge and ballast water? Ballast will contain the residue of what was originally in the fuel tank. This will be either distillate or diesel fuel.[1] Bilge water has been characterized in this report (Chapter Six) as containing distillate, JP-5, or diesel oil. The presence of lubricating oil can be assumed particularly when a ship is underway. NSFO, is presumed to be found in appropriate bilges by analogy.

   2. Comparison of Evaporation Characteristics
       of Crude and Navy Oils

      Research to date on the behavior of oil at sea has been done primarily with reference to crude oils. This is reasonable since the primary sources of oil discharges, both intentional and accidental, are oil tankers and oil well blowouts. A comparison of crude and Navy oils is needed to apply field observations to the Navy's specific problem.

_____

   [1]Completion of the conversion from NSFO to distillate fuel is projected for fiscal year 1973.

The evaporation characteristics of Navy fuels can be inferred by comparing their boiling ranges with the boiling ranges of typical crude oils for which evaporation rates have been studied. "Crudes such as Libyan Zeltan (Brega) and Nigerian light yield relatively low percentage weights of residue after evaporation. Fractions with boiling points less than 700°F will be removed relatively rapidly by evaporation" [Berridge, et al, 1968]. Evaporation will remove 62.5 percent of the Libyan Zeltan crude oil and 64.2 percent of the Nigerian light relatively rapidly. To apply this observation to Navy fuels, examine the maximum boiling point values for JP-5, diesel and distillate fuels. All fractions of JP-5 must have a boiling point less than 550°F. Ninety percent of diesel fuel has a boiling point below 675°F, and one hundred percent must have boiling points below 725°F. The heaviest fuel, distillate, has fifty percent of the weight of its fractions boiling at temperatures below 644°F and ninety percent boiling below 740°F. Using Berridge's observations, for distillate, about seventy percent of the oil will evaporate "relatively rapidly." Diesel fuel and JP-5 will evaporate entirely in a relatively short period of time.

C. DEGRADATION OF OIL IN THE OPEN OCEAN

In the open ocean various processes operate to reduce oil to harmless and sometimes even useful components. The major processes will be examined with particular reference to their effects on bilge and ballast effluents.

1. Evaporation

As previously mentioned, evaporation will remove a
large proportion of distillate and diesel. To quantify the
"relatively rapid" estimate of Berridge, examine the observed
rates of evaporation supplied by Smith and MacIntyre [1971].

They noted that after six hours at sea, 96.1 percent of
decane ($C_{10}H_{22}$), 85.4 percent of hindecane ($C_{11}H_{24}$), and
58.4 percent of dodecane ($C_{12}H_{26}$) were lost from the oil
slick used in the experiment. During the six hours observed,
the wind increased steadily from one to eighteen knots. A
similar experiment conducted by the Institute of Marine
Science of the University of Alaska noted that "Evaporation
readily removes components smaller than C-12 within eight
hours" [Kinney et al, 1969]. This observation was from an
experimental spill of crude oil in Cook Inlet. (No wind or
weather conditions were specified.)

Figure 4-1 shows how the observed evaporation rates can
be applied to Navy fuels. Using the heaviest of future Navy
fuels (distillate) as a reference, it can be seen that most
fractions boil below 418°F. The position of the decane
marker, however, shows that the majority of distillate com-
ponents are larger than C-10. Many environmental factors
such as exposed surface area, wind speed, temperature, and
turbulence will all influence the evaporation rate. A
single universal evaporation rate cannot be established.
It can be inferred that for highly dispersed, relatively
light petroleum products such as Navy fuels, evaporation
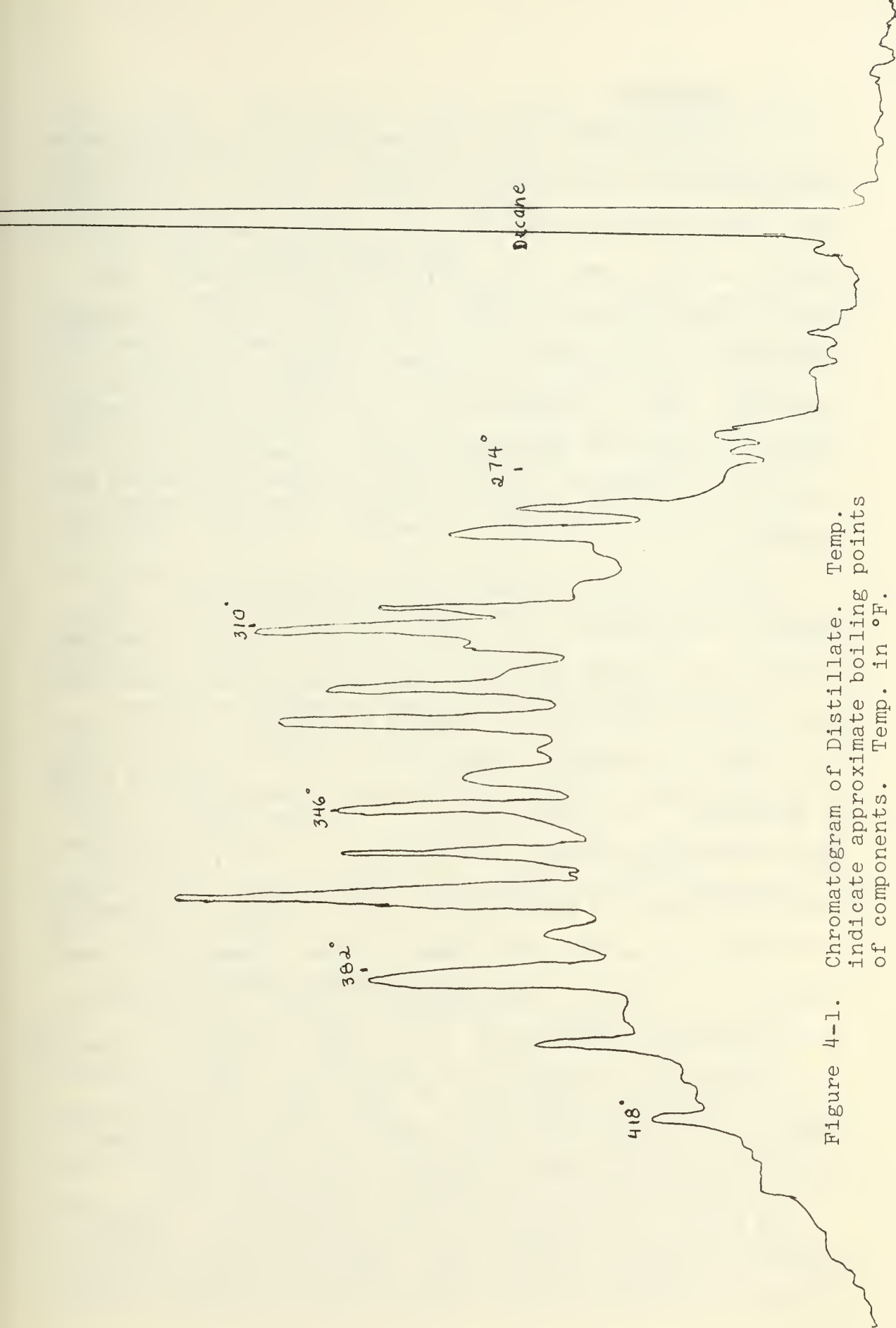will be a significant removal process.

Figure 4-1. Chromatogram of Distillate. Temp. indicate approximate boiling points of components. Temp. in °F.

2. Oxidation

Oxygen reacts with hydrocarbons in the liquid phase.
The products of the oxidation process will be, for the most
part, water soluble compounds, e.g. acids, carbonyl com-
pounds, alcohols and peroxides, or carbon dioxide. The
speed of the oxidation process will be a function of several
variables. Sunlight will increase the rate by photo-
oxidation. The oil composition, the exposed surface area,
and the presence of inhibitors (sulfur compounds) or
catalysts (vanadium, nickel) strongly affect the rate of
oxidation.

There is a lack of quantitative information for the
oxidation reactions. The order of magnitude in comparison
to the other factors degrading oil has not been established.
What would be the effect of adding a catalyst, or emulsify-
ing during the discharge process? The only available guess
is Berridge's. He states that ". . . there can be a wide
range of oxidation rates in the sea. . . . It is prohibi-
tively difficult to estimate the absolute rate of oxidation
of a crude oil on the sea because of the diversity of these
effects. . . . At sea temperatures of about 50°F, however,
it is unlikely, particularly in the early stages of exposure,
that atmospheric oxidation is as important a factor in
removing oil as are the predominantly physical processes
such as evaporation and spreading" [Berridge, 1968].

The Navy is not faced with the difficulty of dealing
with a wide range of crude oils. There will soon be only

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three fuels. Estimates of their overall evaporation and oxidation rates under average oceanic conditions should be the subject of further investigation.

3.   Oil in Water Emulsions

A ship underway with mixtures of diesel or distillate and water in the bilges or ballast tanks will normally pump an oil in water emulsion as its effluent. This type of emulsion can assist in speeding up the physical, chemical, and bacterial processes operating to degrade the oil by providing a greatly increased surface area. If oil was discharged as droplets with a diameter of one micron, for example, it would be invisible, and represent a million fold increase in surface area over the bulk oil of the same mass.

Shoreline damage has been caused by stable water in oil emulsion as opposed to oil in water emulsions. This is the "chocolate mousse" of Torrey Canyon fame. The physical properties of Navy fuels (surface tension, viscosity, pour point, etc.) and the small quantities of oil discharged will not lead to water in oil emulsions.

4.   Microbial Modification

Microbial degradation is a process that is more common in coastal and harbor waters but can be readily adapted for the open ocean. "Virtually all kinds of hydro-carbons from many (oil) fields are susceptible to microbial oxidation. Enrichment cultures consisting of several different species growing under optimal conditions tend to convert crude oils and refinery products mainly to carbon

dioxide and biomass"[Zobell, 1969]. For microbial modifi-
cation, a suitable culture of microbes is required. Less
than five percent of sea water samples taken beyond the
continental shelves contained oil degrading microbes. A
mixed culture of microbes specially tailored to degrade
bilge and ballast oils will have to be developed. Tests
can be made to determine the most efficacious culture and
the optimum time to insert the culture (i.e., before or
after discharge). Other environmental factors can assist
in maximizing the efficiency of the microbes. A note of
caution; aerobic microbes only should be used lest some
ship find its fuel converted to biomass by anaerobic
microbes.

>   a.   Environmental Considerations for Microbial
>   Modification.

>   (1) Toxic Substances. Toxic substances in
crude oils, when mixed with sea water in proportions of one
to fifty or more are not generally enough to prevent micro-
bial growth [Zobell, 1969]. The toxic or growth inhibiting
concentration of diesel and distillate must be established
for a particular mixed culture. Bilges will have to be
kept free of other toxic substances.

>   (2) Oxygen. Oxygen can limit microbe activity.
With the extremely thin oil film associated with diesel and
distillate bilge and ballast effluents and the supersatura-
tion of oxygen in the upper layers of the open ocean, an
abundant supply of oxygen is insured.

(3) _Dispersion_. Breaking oil into small droplets and emulsifying it with sea water renders the oil more susceptible to enzyme attack. "A large air surface helps place more oil in contact with the aqueous media and with atmospheric oxygen" [Zobell, 1969].

(4) _Temperature_. Temperature can be an important factor on the rate of microbial activity. Higher temperatures usually result in higher growth and subsequent oxidation rates. This can influence the decision to insert the microbe culture in the bilge before discharge or insert it on the discharge side of the pump.

(5) _Nutrients_. Nutrients are required for microbial activity. Carbon is present. Ca, Mg, K, S, and Fe are normally present in sufficient quantities in sea water. Nitrogen and phosphorous might have to be added. "The nitrogen and phosphorous requirements of most oil oxidizers are satisfied by the addition of several parts per million of ammonium phosphate" [Zobell, 1969].

b. Summary

Zobell sums up his research by stating: "Microbial degradation is most efficient in removing relatively low concentrations of oil on the surface of water or on solid surfaces. . . . Enrichment cultures which have been 'trained' to attack the various kinds of hydrocarbons most likely to be present in an area are most effective. "The rates of microbial removal were at least twice the rates of evaporation. The largest rates of oil

removal occurred during the initial growth periods. This was attributed to the utilization of n-paraffins smaller than C-18" [Kator, et al, 1971]. These are the results obtained from simulated field studies done in a large outdoor tank containing nine hundred liters of sea water.

   c. Advantages

    The advantages of microbial degradation are numerous. To list some:

  1. Once developed, the mixed culture would be inexpensive.

  2. No changes to existing piping or pumping systems would be required.

  3. No weight or space modifications would be required to transport or store the culture.

  4. The end result would not be subject to shifting oil pollution standards.

  5. The description of an ideal growth situation fits bilge and ballast effluents.

  6. The Navy utilizes fuels that meet well defined specifications. A precise mixed culture to fit the fuels could be developed.

  7. The same mixed culture would serve equally well in case of an accidental spill during a refueling operation or be useful for in port oil spills.

D. RESULTS OF OPEN OCEAN DISCHARGES

  So far, the individual processes acting on oil which has been discharged into the open ocean have been covered. The

results of some spectacular oil discharged into the open
ocean have been recorded. The environmental impact of two
of the best known discharges will be synopsized.

1. Torrey Canyon

Investigators of the Torrey Canyon spill observed
that the organisms affected were connected with the sea
surface. Birds were the most conspicuous of the species
damaged. Other damage was noted to the phytoplankton
associated with the sea surface, and to pilchard eggs,
which also are found at the sea surface. Damage to life
forms, other than those in contact with the sea surface
was not observed. Fish caught immediately beneath the oil
slick showed no tainting [Spooner, 1969].

2. Santa Barbara Channel

The second spectacular oil discharge was in the
Santa Barbara Channel. On January 28, 1969, an oil well
blowout released a large quantity of oil in the channel.
A California Department of Fish and Game survey "indicated
no adverse effects on the anchovy population as a result
of the oil leak." The U.S. Bureau of Commercial Fisheries
found no gross departure from the expected specific compo-
sition of the icthyoplankton in the Santa Barbara Channel.
Three surveys conducted since the oil spill (compared with
twelve conducted before it took place) indicate a greater
biomass than ever before [Straughan, 1971].

3. Application of Field Observations to
    Bilge and Ballast Discharges

From these two incidents and their environmental
repercussions, the following inferences may be drawn:

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1. The consequences in the open ocean of these monumental oil spills were not severe.

2. The disastrous consequences occurred when large quantities of oil entered the intertidal areas.

3. The damage from a dilute, readily degraded, smaller amount of oil discharged over fifty miles from land is probably not a serious environmental threat.

E. EXPERIMENTS ON THE COHERENCE OF OIL AT SEA

1. Warren Spring Experiment

A controlled experiment on the coherence of oil at sea was carried out by the Warren Spring Laboratory (advisor to the British delegation to the Inter-Governmental Maritime Consultive Organization, IMCO). It investigated the one hundred parts per million (ppm) maximum limit of permanent oil in the ballast discharges of a vessel. Oils tested were crude, heavy bunker, lubricating and light marine diesel. Discharge concentrations varied between twenty-five and one hundred ppm. A summary of results follows: "Under all conditions experienced during the trials, emissions of the one hundred ppm could be seen as a continuous, coherent slick. . . . It was determined that the concentration of oil in water had no bearing on the visibility of the resulting slick. The visibility was determined by the final surface concentration of the oil on the sea so it can be related to the actual amount of oil discharged per unit distance of ship's travel" [Smith, 1971].

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2. U.S. Coast Guard Experiment

The U.S. Coast Guard conducted an experiment similar to the Warren Spring experiment. The objective was to detect oil slicks and obtain legal evidence of excessive discharges in order to prosecute violators. Their findings confirm the observation that the oil flow to produce a slick of specific intensity is directly proportional to ship speed and the actual amount of oil discharged. The report also notes that an attempt to detect a gasoline spill was unsuccessful because the gasoline did not remain coherent enough to obtain a photographic record [Catoe, 1971]. It should be kept in mind that JP-5, diesel and distillate are more akin to gasoline than they are to heavy, persistent crude oils.

F. LEGAL DISCHARGE RATES

The maximum discharge rate of oil into the open ocean as stipulated by the International Convention for Prevention of Pollution of the Seas by Oil, 1954, as amended in 1962 and 1969, is sixty liters (approximately 15.8 gallons) per mile. The discharge must take place more than fifty miles from land. This limit on the discharge rate is aimed at oil tankers carrying crude, persistent oils. The basis for the limit is the Warren Spring experiments, which resulted in the observation that the open ocean can cleanse itself of this amount of oil in the space of several hours.

The sixty liter per mile limit was examined without attempting to adjust for the greater volatility of Navy fuels. A ship steaming at seventeen knots could pump

4.57 gallons of oil per minute without violating the Convention. Assuming a bilge or ballast concentration of one hundred parts water to one part oil, a Navy ship could pump bilges or ballast tanks at a rate of four-hundred fifty-seven gallons per minute. This far exceeds the normal need (or in many cases, the ability) to pump ballast tanks or bilges.

G. CONCLUSIONS

Bilge and ballast effluents may be discharged in the open ocean without causing any environmental damage. It appears unnecessary to expend large sums of money to install oil-water separators, or arrange for holding tanks and install the accessory piping and pumps to link the bilges with the holding tanks. There are four major reasons for this conclusion.

1. Oil does not accumulate in the ocean. The ocean provides a surface for evaporation and oxidation, and a potential surface for biodegradation. In some cases the oil actually can act as a nutrient to increase the biomass.

2. International agreements are based on observations of the behavior of crude oil at sea. Without adjusting the standard for the more volatile character of Navy fuels, it is apparent that the Navy still complies with the agreements.

3. The funds can be much more effectively employed in other pollution abatement programs.

4. Before any formal agreements banning all oil dischar-
ges on the open ocean are concluded, a thorough
study of the environmental effects of such dis-
charges should be conducted.

III. U.S. COASTAL AND HARBOR WATERS

Section I stressed the open ocean's powers for ridding itself of oil contamination. When oil is discharged into shallow, confined coastal or harbor waters, the results are often disastrous. The natural removal processes may not have sufficient time or surface area to operate before local flora and fauna are destroyed. The lighter oil fractions that permitted rapid degradation in the open ocean can also exert a more toxic effect in confined waters.

The objective of this section is to examine the Navy's contribution to harbor oil pollution and suggest methods for abatement. To gain perspective, three incidents where oil reached confined waters are reviewed. An example of chronic low level oil pollution is given. Next, the expected effects of a distillate spill are compared with the results of NSFO spills. The final section uses the conclusion of Chapter Ten, which is that the Navy should contract out oil spill cleanup operations. The initial containment phase of pollution abatement is covered. Oil spreading rates and boom selection criteria will be examined. Emphasis is on

the most efficient and economical measures to provide com-
plete containment.

A. INCIDENTS WHERE OIL HAS ENTERED COASTAL OR HARBOR WATERS

   1. Santa Barbara Channel

      On January 28, 1969, there was an oil well blowout
from a platform in the Santa Barbara Channel. By February 8,
1969, an estimated 4,508 metric tons of oil came ashore
between El Capitan and Port Hueneme, a distance of about
sixty miles. Extensive surveys were conducted on the biota
of the open ocean and the inter-tidal areas. As previously
mentioned, there was no observed damage in the open ocean
(except to birds). The survey did find significant mortality
in the intertidal areas, particularly to the barnacle
(Chthmalus fissus), the marine grass (Phyllospadex torreyi)
and the marine algae (Hesperophycus harveyanus). Recolon-
ization of the intertidal area commenced within seven weeks
of the spill, and "As of November, 1970, most intertidal
areas now have a normal population" [Straughan, 1970].

      Several factors are believed responsible for the compara-
tively light damage and quick recovery of the intertidal
areas. The oil floated for several days, allowing the more
toxic aromatic fractions to evaporate. There is a natural
oil seepage in the area, and the local biological populations
have built up a tolerance for oil. The seepage gives rise
to a large indigenous population of oil degrading bacteria
which have been naturally selected to operate on the type
of oil that was discharged. The damage done in the intertidal

areas was due to smothering rather than the toxicity of the
oil. The greatest damage from the incident was to the
esthetic and recreational value of the shoreline.

   2. Torrey Canyon

      The Torrey Canyon spillage follows the same general
outline as the Santa Barbara Channel incident. There was
no serious damage in the open ocean (again excepting birds).
Toxic detergents and the smothering effect of oil caused
some damage to intertidal species. "The balance of shore-
line life was upset and the rocks made dangerously slippery
for several years, but . . . though recovery is not yet
complete, it is unlikely that any serious permanent damage
will have occurred even after the colossal spillage exper-
ienced after the Torrey Canyon went aground" [Spooner, 1969].

   3. Grounding of the Florida

      A far more disastrous spill occurred on September
16, 1969. The barge, Florida, transporting No. 2 diesel oil
grounded off West Falmouth, Massachusetts. No. 2 diesel oil
is a light distillate with an aromatic hydrocarbon content
of 41 percent, specific gravity of .86 and kinematic vis-
cosity of 4.3 centistokes at 60°F. This bears a strong
resemblance to Navy distillate fuel. An estimated 650,000
to 700,000 liters of oil was spilled. A southwest gale
carried much of the oil towards West Falmouth Harbor and
Wild Harbor. "After the spill a drastic kill of fish, worms,
crustaceans, and molluscs was noticed almost immediately"
[Blumer, et al, 1970]. Even though an attempt was made to

boom off both harbors, the kill-off extended into the inshore areas upstream of the floating booms. The gale force winds caused intense mixing as evidenced by the fact that oil was incorporated into the sediments in water depths as great as ten meters. In addition to the overall biological damage, commercial shellfish beds were either destroyed or closed because of tainting [Blumer, et al, 1970].

Some of the observations made in investigating this disaster can be applied to our particular oil pollution problem. After nine months the oil found in the sediments was essentially unchanged. Bacterial attack had not altered the oil. One possible explanation is that during the initial spill and turbulent mixing, the toxic fractions of the oil killed off the oil degrading bacteria. Oil was being released from the sediments long after the spill, preventing repopulation and, in fact, even extending the devastated area. Light, distillate fuels become thoroughly dispersed throughout the water column and can even be incorporated in the sediments if there is sufficient turbulence. Containment booms are ineffective during adverse weather conditions.

A spill of this magnitude of Navy distillate or diesel fuel under similar weather conditions is not a strong possibility. But quantification of the turbulent diffusion of both fuels, under normal and adverse harbor conditions is necessary. Refueling or fuel shifting operations should be curtailed, if possible, when the weather is bad. Rapid containment in a still water area of any spill that does

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occur is a paramount consideration particularly when wind
and seas indicate substantial turbulent diffusion will
occur outside the slip area. Distillate and diesel fuel
both will be readily incorporated into the water column,
by turbulence, with serious consequences.

B. CHRONIC LOW LEVEL POLLUTION

In addition to dealing with the effects of large, acci-
dental spillages, the damage caused by continuous exposure
to low concentrations of oil must be considered. Small
patches of oil can generally be observed in busy Navy harbor
areas. Small spills, dripping fuel lines, unauthorized
bilge discharge, and inefficient donuts all contribute to
chronic low level pollution.

1. Milford Haven Study

A study of the effects of continuous low level pol-
lution was done in Milford Haven, U.K. Effluent from (1)
rain washing down a refinery area, (2) ballast water from
tankers and (3) process water condensed from steam injection
in the refining operation was discharged into Milford Haven.
The discharge concentration never exceeded 50 ppm and was
usually between 20 and 25 ppm. The total amount of oil
discharged was estimated at 1680 bbl (350,000 liters)
annually.

The area surrounding an outfall located in a small
sheltered bay was investigated. A pollution gradient was
observed with the severest depletion of flora and fauna
being right at the outfall. A second outfall discharged

jettyhead and operated only on the ebbing tide. "No bio-
logical changes in the intertidal zone were found that could
be attributed to the outfall water. . . . It was concluded
that with effluents containing oil levels of 20-25 ppm,
biological damage occurs only if the effluents are dis-
charged at the shoreline in areas of poor tidal dispersion"
[Cowell, 1971].

2. Application of Milford Haven Observations
    to San Diego Naval Station

To view this potential pollution hazard in perspec-
tive, take some estimates for the Naval Station in San Diego.
Assume an average daily ship population of fifty ships, each
with a requirement to pump 1,000 gallons of bilge water per
day. If an oil-water separator with the ability to reduce
the water effluent to 20 ppm was employed, the daily dis-
charge of oil from bilge pumping would be:

(50 ships) x (1,000 gal per day) x (20 ppm) = 1 gal/day

or approximately 6.64 bbl per year. The oil separated in
this process would have to be eventually taken ashore and
reclaimed or disposed of there.

The question now arises: is the savings in bulk trans-
port (i.e., taking only the separated oil ashore vice the
entire bilge load) worth the installation of oil-water
separators and the piping and pumping systems required for
their operation? As has already been mentioned, oil-water
separators are unnecessary on the open sea. Before deciding
on the appropriateness of oil water separators for ships
in port, recent legislation should be reviewed.

3. Legal Guidelines on Low Level Pollution

A recently passed measure (S2270) in part reads, "The objective of this act is to restore and maintain the integrity of this Nation's waters . . . (1) the discharge of toxic pollutants into navigable waters [must] be eliminated by 1985 . . . (3) the discharge of toxic pollutants in toxic amounts be prohibited" [Congressional Record, 1971]. As noted in the Milford Haven studies, 20-25 ppm of oil in water can be considered toxic, hence the Environmental Protection Agency in applying this act will likely use similar standards.

4. Is a 20-ppm Effluent Realistic?

Implicit in the preceding discussion is that 20 ppm effluents can be readily achieved by oil water separators. This assumption must be scrutinized. The solubility values of Navy fuels must be considered. An experiment was run with the purpose of obtaining still and turbulent values of the amount of oil in sea water.

a. Turbulent Values

Samples were prepared by mechanically shaking distillate and NSFO and seawater for twenty-four hours. The sample was then allowed to stand for twenty-four hours. A sample was siphoned from the visibly clear sea water portion of the mixture and put in a separatory funnel. A sample was then drawn from the funnel. This allowed any oil carried over in the siphoning process to be eliminated. A continuous ether extraction was then run on the sample for seventy-two

hours. The ether was allowed to evaporate and the weight of the residue was compared to the weight of the original sample to obtain ppm values. The end point of the ether evaporation was determined by daily weighing of the samples on an analytical balance. If ether was still evaporating, a weight loss could be observed on the balance. When the sample was placed on the balance and the weight remained steady, the ether evaporation was considered complete. Some of the more volatile components of the oils were probably lost with the ether. The values given are probably lower than the actual residue. The values obtained by this procedure were:

NSFO - 1099 ppm   NAVY DISTILLATE - 2631 ppm

b. Solubility Values

Samples were prepared by allowing an oil-water mixture to stand for thirty days. A sample was drawn from the sea water portion of the mixture, and the ether extraction procedure described in a. was used. The results were:

NSFO - 63 ppm   NAVY DISTILLATE - 539 ppm

From this, it is concluded that for Navy distillate a 20-ppm effluent standard is not a realistic goal. High capacity separators cannot remove oil that is actually dissolved in water.

5. Conclusion

The installation of shipboard oil-water separators would not be an effective pollution control measure. The advantage of the separator is to reduce the bulk of bilge

mixtures that must be taken ashore. To achieve this advantage, it would be necessary to install the separators, pipes, and pumps, and arrange for a holding tank. It assumes that the water separated during the process would be safe to discharge. This may not be the case. Standards could be set that would declare the separated water a "toxic pollutant in toxic amounts." As has been noted, 20-ppm effluents can be toxic. If the separated water cannot be discharged, there is absolutely no reason for the shipboard separators.

Shipboard oil-water separators are unnecessary on the open ocean and will probably not be capable of meeting future harbor standards. For ships in port the alternative of taking the entire bilge load ashore is the avenue with the most promise. Elaborate separation procedures, coupled with biodegradation, can be accomplished in the uncramped quarters of a shore facility. No ship modifications will be needed, and Navy ships would be allowed to persue their primary mission without this impediment.

C. BIOLOGICAL IMPACT OF DISTILLATE AND DIESEL SPILLS IN PORT

1. General

The results of the Florida spill indicated that distilled petroleum products would be an order of magnitude more toxic than the residual NSFO. Specifically, would a distillate spill greatly damage the environment where NSFO had only a transient effect? Experiments were conducted to compare distillate and NSFO in terms of dispersive characteristics and their toxic effects on a common intertidal species.

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2. Comparative Toxicity of Distillate and NSFO

Mixtures of distillate and NSFO were prepared in
concentrations of 1,000, 500, 375, 200, 100 and 50 ppm. Into
the mixtures were placed 20 hermit crabs (Pagurus Samuelis).
Each day the crabs were removed from the mixture, examined
for signs of life, and returned to a freshly prepared mixture
of the same concentration. The crabs in the beakers with
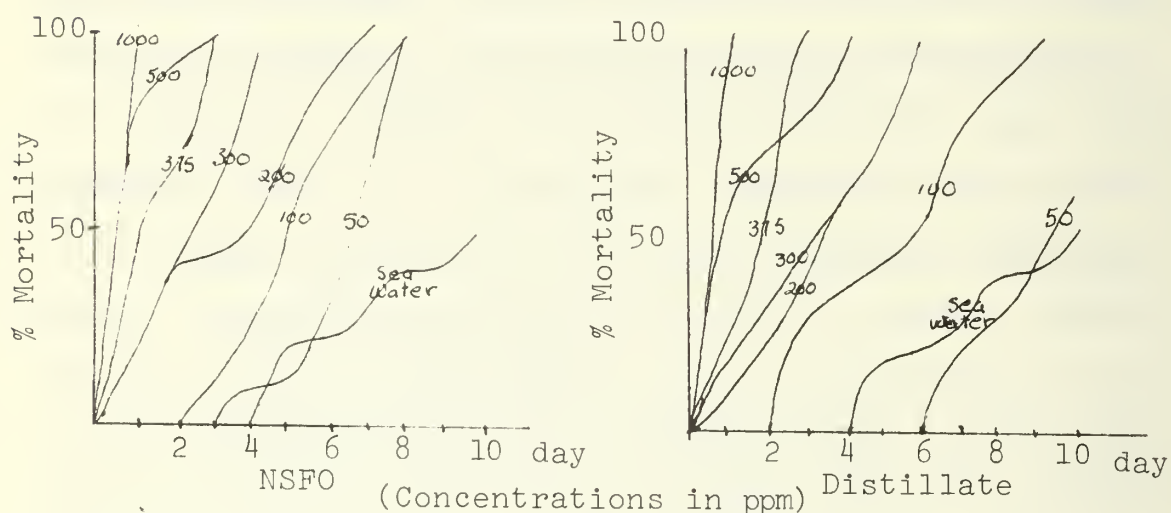
Figure 4-2. Comparative Toxicities.

NSFO AND distillate mixtures were kept under identical con-
ditions as a control group in sea water. Figure 4-2 is a
graph of the percent mortality versus time for each concen-
tration used. Comparing the graphs for NSFO and distillate,
it does not appear that distillate is intricsically more
toxic. But since distillate will be found in greater con-
centrations in the water column, it will exert a more toxic
effect. As a result, rapid containment before distillate

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can be dispersed into the water column becomes extremely important.

D. SPREADING OF OIL SLICKS

The need for rapid containment of an oil spill has been noted. Contingency plans for dealing with a distillate spill must take three horizontal spreading factors into account. Initially, oil will spread due to a pressure head in an attempt to achieve an equilibrium thickness. This is opposed and eventually balanced by viscous and frictional effects. Wind and current will then move the slick. This section will quantify each spreading process and establish rules for containing a slick.

1. Initial Spreading Force

Initial spreading is a function of the physical properties of the oil. An examination of the differing properties between distillate and NSFO clearly indicates distillate will spread more rapidly than NSFO. Distillate has a density of .85 while NSFO has .96. This means distillate will have a greater buoyancy and hence a greater "pressure head" resulting in a more rapid flow rate. Distillate has a viscosity of 1.7 Cs; while NSFO has a viscosity of 30 Cs (Centistokes at 100°F) [Quarto and Duncan, 1971]. Hence the spread of distillate is less inhibited by viscous effects. Laboratory measurements show the surface tension of distillate to be 27.1 dynes per centimeter and NSFO to be 34.3 dynes per centimeter. The equilibrium thickness of NSFO will be greater due to its larger cohesive

force. Speed of deployment is more important with distillate than it is with NSFO, due to the greater spreading rate.

      e. Berridge Experiments.

      Berridge uses an empirical formula derived by Blokker to estimate the spreading rates for various crude oils. The physical properties of a particular oil (surface tension, kinematic viscosity, interfacial tension and density) are accounted for in a derived constant. The constant is obtained by using the formula:

$$K_r t = \frac{\pi(r_t^3 - r_o^3)\rho_w}{3V(\rho_w - \rho_o)\rho_o}$$

where r_o, r_t = slick radius

          V = oil volume

          t = time of spreading

          ρ_o, ρ_w = densities of oil and water

          K_r = constant for any given oil

From this expression Berridge derives K_r's for various crude oils at 5 C.°

Crude Oil	K_r
Libyan	1085
Iranian heavy	750
Kuwait	1480
Iraq (Kirkuk)	975
Venezuela	1340

[Berridge, et al, 1968].

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b.   Application to Distillate and NSFO

Berridge's results can be applied to distillate and NSFO by matching the relevant physical parameters that control the initial spread of oil (i.e., viscosity, density, surface tension, and interfacial tension). Distillate is best approximated by Libyan crude, and NSFO resembles Iranian heavy. Consequently, in the following discussion, a K_r of 1085 for distillate and 750 for NSFO will be used.

c.   Experiments with Distillate and NSFO

An experiment analogous to Berridge's empirical derivation of K_r's for crude oils was conducted. NSFO and distillate were released, sluice gate fashion, from one end of a wave tank. One liter of oil per run was used. Scribe marks spaced at intervals along the wave tank were used to gage distance covered. The time between successive scribe marks was measured on laboratory timers accurate to one tenth of a second. A variation of the experiment had oil poured at the rate of one liter per ten seconds to gain a qualitative estimate of the spreading rate differences between a poured (or pumped) oil spill and one released sluice gate fashion.

The confined channel flow of the wave tank experiment can not be directly correlated with the unimpeded circular spreading of Berridge's experiment due to the difference in geometry. Results showed the K_r approximations mentioned in b. to be of the right order of magnitude and probably greater than what can be expected for distillate and NSFO.

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The experiment did confirm that distillate will spread almost twice as fast as NSFO. A pumping spill will have a diminished spreading rate as compared to a sluice gate type discharge.

    d.   Limitations of Berridge's Formulation

The wave tank experiment revealed a serious limitation on Berridge's formulation. Distillate and NSFO both exhibited the same characteristic. Initially, the oil spreads rapidly until a sharp break point in the spreading rate occurs. Figures 4-3 and 4-4 illustrate this character-istic. The break point will be called the initial equili-brium thickness. At this point, while spreading is still going on, its rate is insignificant in comparison to the wind and current forces and can be safely ignored in planning containment measures.

(1) <u>Initial Equilibrium Thickness</u>. When dis-tillate duel has reached a thickness of .29 centimeters and NSFO has reached a thickness of .39 centimerers, a sharp reduction in the rate of spreading was noted. The formula $K_r t = \dfrac{\pi(r_t^3 - r_o^3)\rho_w}{3V(\rho_w - \rho_o)\rho_o}$ with its straightforward dependence on time does not adequately describe spreading beyond the initial phase. In the experiment, distillate spread to a thickness of .29 centimeters in 10.6 seconds. The average velocity during the initial phase was 11.5 cm/sec. One hour following the initial spreading phase, the slick thick-ness was reduced to .15 centimeters. The average velocity was .02 cm/sec. This velocity is considered insignificant and can be ignored in devising a containment plan.
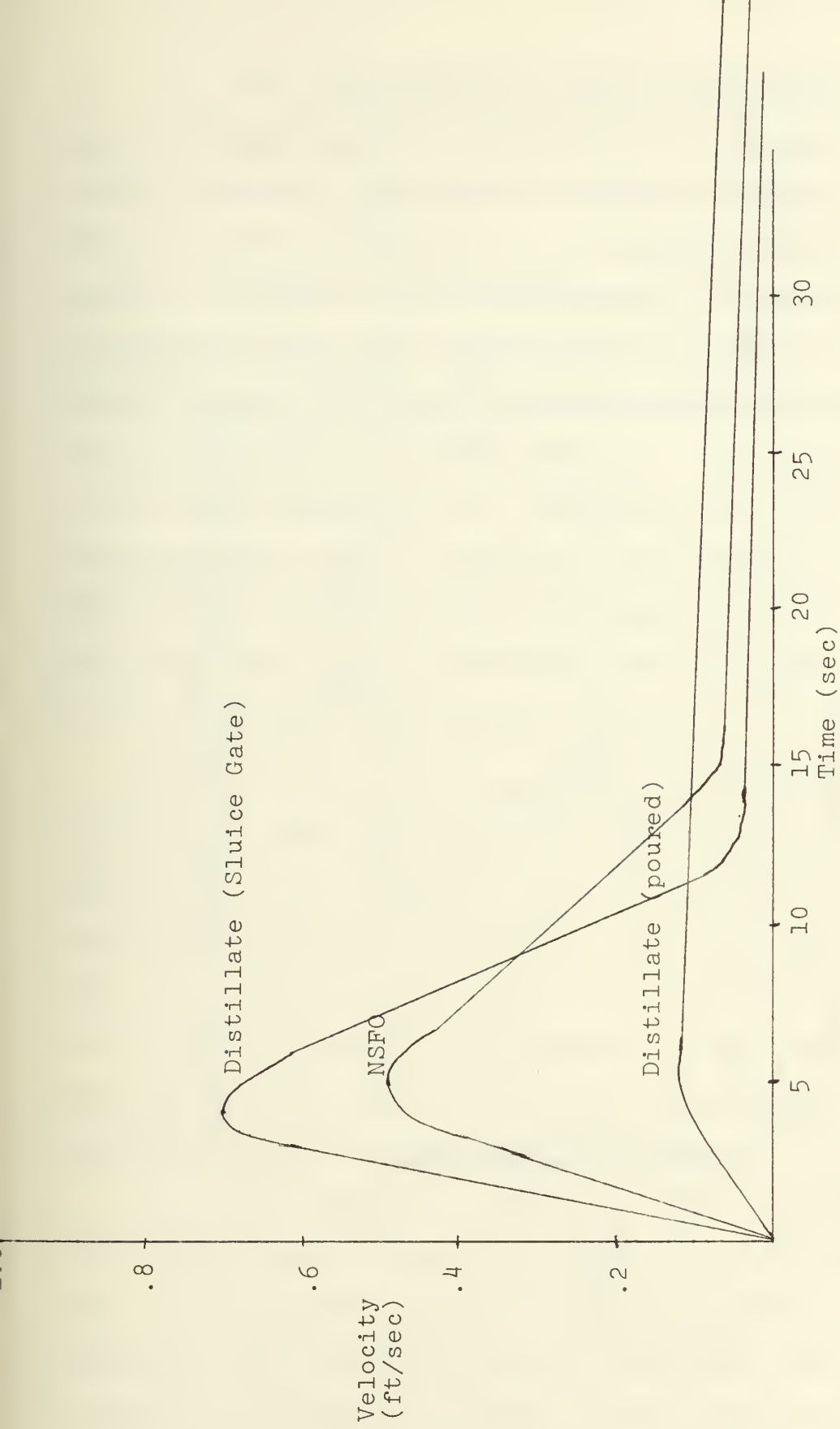
Figure 4-3. Velocity vs Time for Distillate and
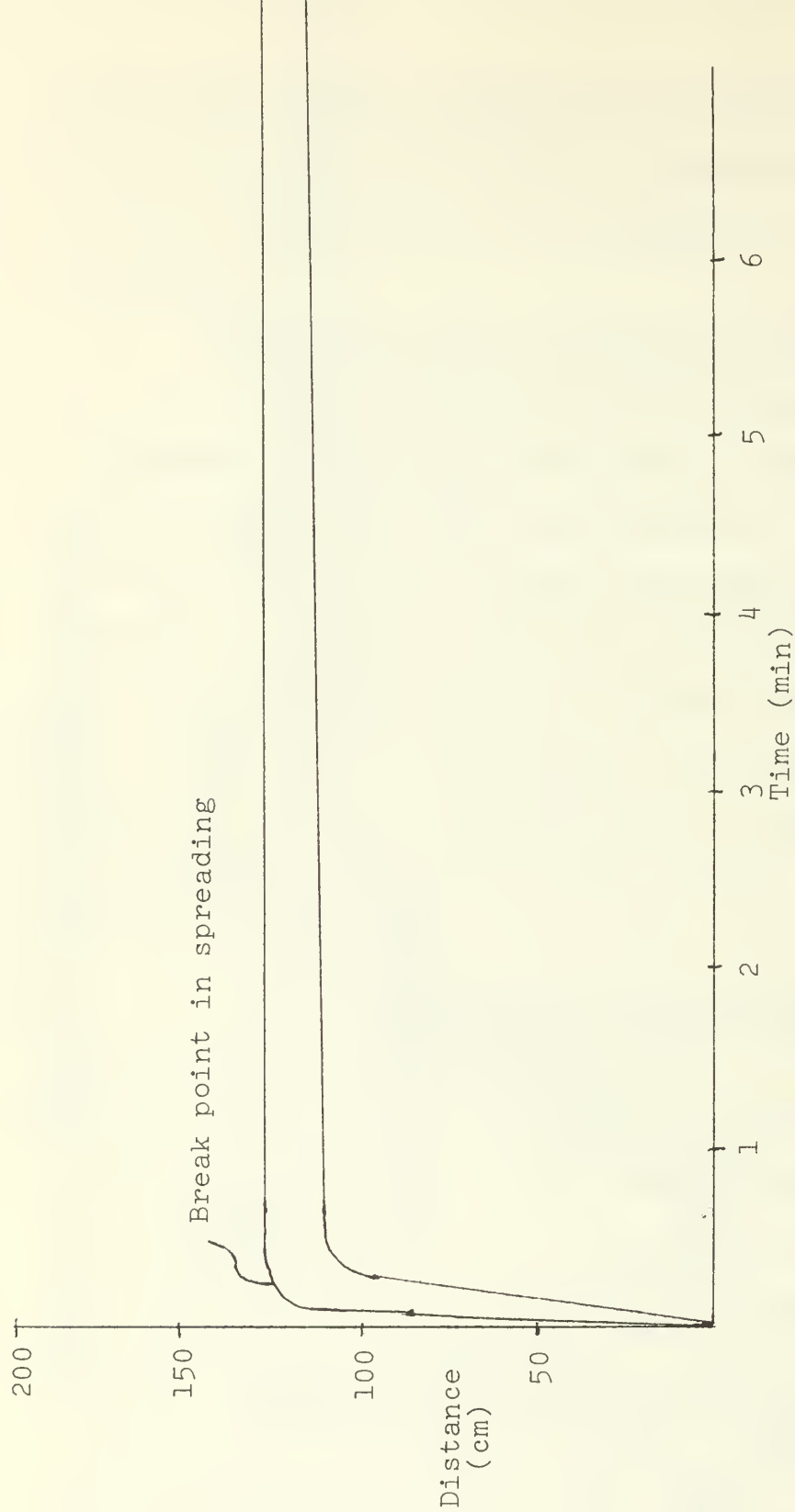NSFO Spreading Experiments

Figure 4-4. Distance vs Time for Distillate and NSFO Spreading Experiments.

(2) <u>Application of Initial Equilibrium Thickness to a Containment Plan</u>. In designing a containment plan, the initial spreading force can be considered expended when distillate reaches a thickness of .29 centimeters and NSFO reaches a thickness of .39 centimeters. If there were a 1,000-gallon spill at a fuel pier and it spread in a semi-circular manner, an estimate could be made as to how far the oil will spread by simple geometry. One thousand gallons is 3.78 cubic meters of oil. For distillate, the initial spreading force will be expended in 28.8 meters or 94 feet. NSFO will have achieved its initial equilibrium thickness in 81.5 feet. Thus for a 1,000 gallon spill, the spreading force will be negligible beyond 100 feet.

Using the formula $K_r t = \dfrac{\pi r_t^3 \rho_w}{3V(\rho_w - \rho_o)\rho_o}$ and the approximate K_r values for NSFO and distillate, an estimate of the time required for the 1,000-gallon spill to reach the initial equilibrium thickness is obtained. For distillate, 46 seconds are required to reach the initial equilibrium thickness and for NSFO, 87 seconds are required. These times are less than will be experienced with a normal pumping spill so using them provides a safe margin for error.

(3) <u>Summary</u>. Immediately after a spill, oil will spread rapidly to achieve an initial equilibrium thickness. In the example cited, a time and distance were calculated upon which an effective containment plan could be based. An attempt to contain a spill during its initial spreading phase will probably not be successful because of

high relative oil-to-boom velocities. The ideal time for containment is soon after the spreading force has been expended and before the wind and current exert a strong effect.

    e. Preparation of a Containment Plan

    Based on the spreading rate for distillate, the following guidelines can assist in designing a containment plan:

1. Determine the pumping rate utilized during the operation.

2. Measure the response time to secure the evolution once the spill is detected. Chapter Eight of this report deals with the recommended alarm devices and emergency shut down procedures.

3. Assume the pumping rate multiplied by the response time to be the volume of oil spilled. This will give a greater spreading rate than is actually the case. Since the spill will be occurring over a period of time, the total buoyancy of the oil will not be operating as one single large, driving force. The assumption of an immediate release of a volume of oil is implicit in Blokker's equation and Berridge's experiment and will provide a safe margin of error here.

4. Knowing the radius of the containment boom, or its distance from the point of the spill, estimate a value of r_t. Then solve for a value of t. This

gives the maximum time available to deploy the boom .
if the spill is to be contained.

5. Working the other way, assume a reasonable time for
boom deployment. With this, obtain the required
boom length or intercept line for effective con-
tainment.

2. Movement of an Oil Slick Under the Influence
of the Wind and Currents

a. Wind

Wind exerts about the same drag over an oil
slick that it does over water. Neglecting the effects of
surface waves, an oil slick moves with the wind at approx-
imately four percent of the wind velocity [Henager et al,
1970]. In preparing a containment plan, take a maximum
wind velocity for ninety percent of the time from clima-
tological data. Four percent of this gives the maximum
velocity the wind will impart to the oil slick under most
conditions.

b. Currents

Oil slicks will move in the direction of the
surface current with about the same velocity as the current.
A summary of maximum currents in Navy ports is available in
local port directories.

c. Local Containment Plans

Summaries of wind and current patterns give an
indication for the speed needed in deploying a boom and the
general area where containment should be effected. It does
not, however, provide a total picture. Currents in slip

areas or behind breakwaters will not be what is listed in general port descriptions. The conditions in an area where the likelihood of a spill is the greatest must be known to locate the optimum containment line. Each location must tailor its containment plan to the particular situation. The expected volume of spilled oil, wind and current data, availability of equipment and personnel, and the relative importance of surrounding areas must be considered in devising a containment plan.

Not only must the plan itself be flexible enough to cope with a variety of wind and current conditions but so must the men who implement it. The on-scene supervisor must be able to recognize which process is dominating and he must initiate the most effective containment procedure.

B. CONTAINMENT BOOMS

Criteria for the selection of a mechanical containment boom and circumstances that cause a boom to fail will be covered in this section. A containment boom represents a considerable capital outlay. Environmental factors must be considered before a boom is purchased. An area with high winds or strong currents will need a heavy duty boom with a deep underwater skirt. Conversely, a cheaper, lighter weight boom may be completely adequate in areas with milder environmental conditions.

    1. Causes of Boom Failure

        a. Failure of Oil to Surface

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As described in Chapter Five, fuel oils and in partic-
ular, distillate have a tendency to break into small drop-
lets when agitated. The oil droplets do not quickly return
to the surface. When dealing with a pumping spill, droplet
formation can be assumed. Water turbulence, particularly
with white capping, will generate distillate bubbles and
distribute them throughout the water column. This difficulty
was amply demonstrated in the "Florida" spill. The common
procedure of herding an oil slick with a fire hose is an
excellent method of generating small oil droplets (Chapter
Five). Small boat activity in the vicinity of the slick
will also distribute oil droplets through the water column.

There are some measures that can be taken to prevent
large quantities of oil from passing under the boom in the
form of droplets. The containment boom should be far
enough from the spill to allow the oil bubbles generated in
the original spill to rise. This will be a function of
current speed, height of discharge point, and pumping rate.
The boom should be deployed in the calmer slip area when
water turbulence exists outside the slip. Obviously some
compromise may be required between which of two bubble-
generating forces is compensated for. Use of fire hoses
should be kept to a minimum near the containment boom.
Small boat activity should be curtailed in the slick area.

b. Boom Failure Due to Entrainment

A headwave in a two-phase density-stratified
flow forms just behind the leading edge of the spreading

liquid. The headwave causes the entrainment of oil droplets.
The droplets can then pass under a boom. To estimate the
entrainment loss, Lindenmuth, et al [1970], made some
simplificaions and obtained:

$$V_e = \beta' u_c t_h$$

where V_e = entrainment rate in ft^3/ft-sec

β' = entrainment coefficient

u_c = current speed in ft/sec

t_h = headwave thickness

t_h is proportional to $\dfrac{u_c^2}{g}$, the proportionality constant is
the densimetric Froude number which in this case is assumed
to be unity. Assuming a stationary boom:

$$V_e = \frac{\beta' u_c^3}{g'} \qquad g' = g(1 - \frac{\rho_o}{\rho_w}) = 5.45 \ ft/sec^2$$

Coefficients were experimentally determined for various oils
at various current speeds. The results are summarized as
follows:

U_c (ft/sec)	β'	SPECIFIC GRAVITY	INTERFACIAL TENSION (dynes/cm)
1.14	.00715	.86	1
1.44	.00748	.86	16
1.23	.00574	.86	16
1.08	.00465	.906	18.8

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The interfacial tension of distillate and sea water was measured in the laboratory is 21.2 dynes/cm. Entrainment is a function of interfacial tension and relative densities. As an example, one can take a 1.44 ft/sec current speed with a β' of .00748 and compute the entrainment loss.

$$V_e = \frac{.00748 \ (1.44)^3}{32 \ (1 - \frac{.85}{1.02})}$$

$$V_e = .004 \ ft^3/ft\text{-}sec$$

This means about .03 gallons will be lost under the boom per foot of boom length in the direct path of the oil slick motion, per second.

Several measures can be taken to minimize entrainment loss. An attempt can be made to contain the spill where there will be a minimum relative velocity between the spreading oil and the boom. This can be achieved by allowing the boom to drift with the current. A skirt depth of about twice the headwave thickness will give a sufficient boom reserve to minimize entrainment loss. Mono-layers or chemical "oil herders" placed between the advancing slick and the boom can retard and even reverse the oil flow. In effect, then, the boom could be containing the mono-layer. The mono-layer , in turn, would contain the oil. Placing absorbent material, such as polyurethane foam between the boom and the spreading oil can damp out slick motions while it initiates the cleaning process.

c. Exceeding the Capacity of the Boom

Wind, currents, and the initial spreading force can cause a failure of the boom by simply exceeding its capacity to hold oil. An investigation of wind set-up of oil reached the following conclusions: (1) the drag coefficient for wind over oil without surface waves is the same as that for wind over smooth water, (2) the formation of surface waves increases the surface wind stress resulting in increased oil set-up, (3) the oil wedge is parabolic in shape. Oil set up due to the wind will be due to the fetch length (length of slick over which wind is blowing) and the relative velocity between the boom and the slick [Sorenson and Spencer, 1971].

The retention capability of a boom in a current was observed to be seriously degraded when the value of $\dfrac{u_c}{\sqrt{g'd}}$

where u_c = current velocity

$\rho_o \rho_w$ = densities of oil and water

g' = $g(1 - \dfrac{\rho_o}{\rho_w})$

d = skirt depth

was greater than 1.3. The boom failed completely when the $\dfrac{u}{\sqrt{g'd}}$ exceeded $\sqrt{2}$ where

u_c = current velocity

g' = $g(1 - \dfrac{\rho_o}{\rho_w})$

d = skirt depth

[Cross and Hoult, 1970].

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d. Effect of Waves

Waves increase the chances for boom failure. Lindenmuth, et al, empirically determined a weighting factor to compensate for waves. The entering argument is wave height vs wave length. Figure 4-5 shows how the weighting factor is derived. It depends on wave height vs wave length.

2. Selection of a Containment Boom

The least expensive boom that will efficiently contain an oil spill is desired. Environmental factors, particularly wind, cur ents and waves will indicate the optimum skirt depth and boom strength for an area. As an illustration, assume an area with two-knot tidal currents and winds of fifteen knots or less ninety percent of the time and an average wave height to wave length ratio of 0.06. Further assuming that the wind and current are acting in concert, and the initial spreading force has been expended, the maximum slick velocity that will be experienced by a stationary boom is 2.0 KTS + .04(15)KTS = 2.6 KTS. Taking the borderline case gives:

$$1.3 = \frac{u}{\sqrt{g'd}} \qquad\qquad d = .92 \text{ ft}$$

A weighting factor of 1.6 is used to compensate for waves; so d must be 1.5 feet. Checking to see if this will be sufficient to prevent entrainment loss yields:

$$t_h = \frac{u^2}{g'}$$

$$t_h = 1.2 \text{ ft.}$$
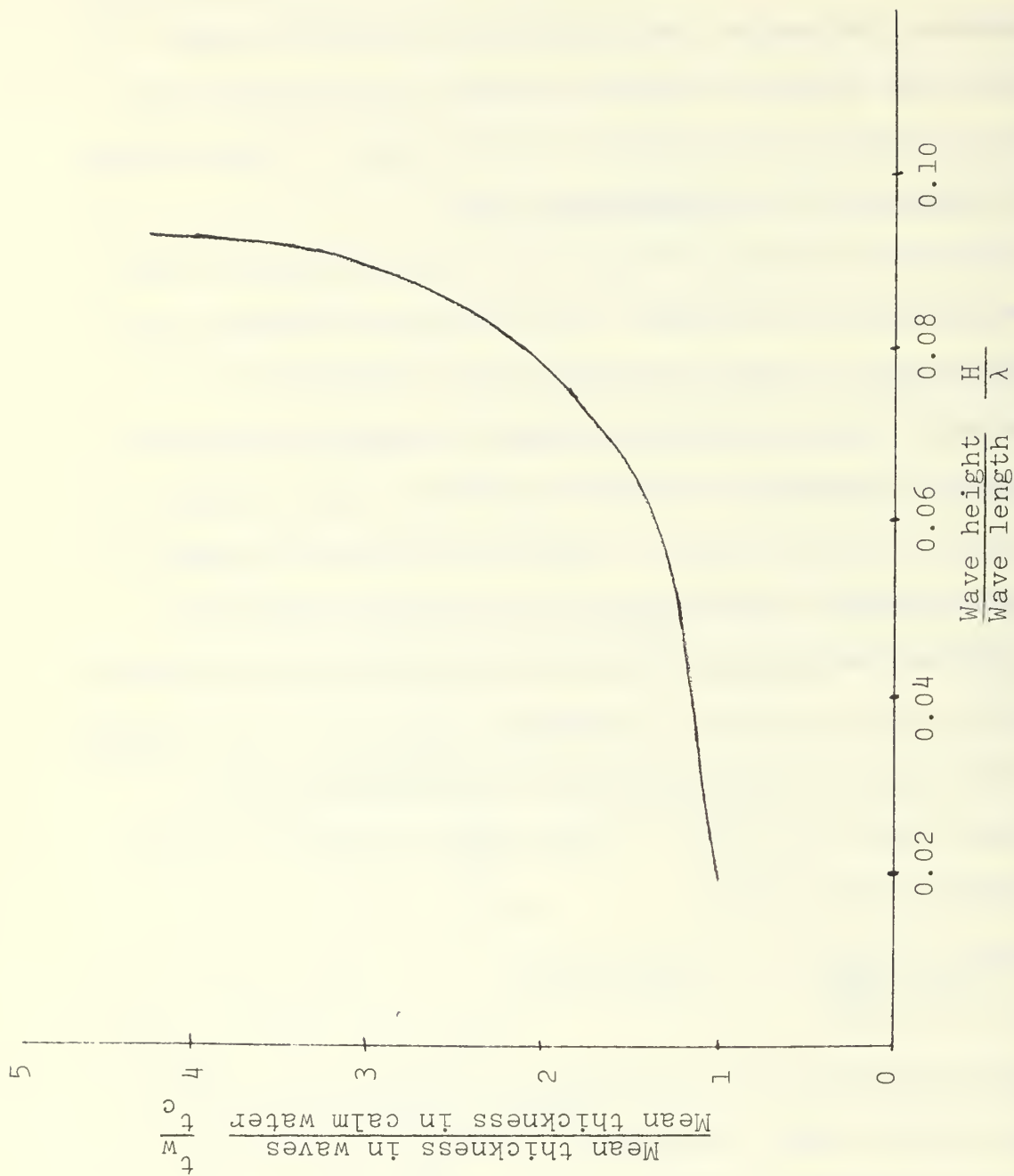
Figure 4-5. Weighting Factor for Presence of Waves.

If the slick is allowed to surge up against the boom at maximum velocity, there will be entrainment loss. Either a deeper skirt will be needed or the initial surge against the boom must be lessened. Mono-layers, sorbents, or allowance for some boom drift can all reduce entrainment loss. Viewed another way, a boom with a 1.5-foot skirt depth will suffer entrainment loss if it is subjected to relative velocities in excess of two knots.

F. CONCLUSIONS

There are three major processes that spread an oil slick; initial spreading, wind, and current. A containment plan must be based on a quantification of the rates of these processes in any given location. The spill size, wind velocity, and current velocity determine the spreading rates. Flexible containment plans should be devised for particular areas based on local environmental data. The key to effective implementation of a containment plan is a knowledgeable on-scene supervisor.

Boom selection should also be made based on environmental data. Oil bubbles passing under the skirt, entrainment, and exceeding the boom capacity negate the effects of a containment boom. Avoiding excessive relative velocities and employing mono-layers and sorbents enhance a boom's oil retention capability.

IV. SUMMARY AND CONCLUSIONS

Studies conducted after two major open ocean oil spills indicate that the damage to the biota from these spills was slight. The environmental processes operating to degrade oil at sea rid the ocean of oil pollution in a relatively short period of time. A dilute, readily degraded form of oil such as will be found in bilge and ballast effluents will not have to be treated on-board before discharge. On-board seperating systems will not be needed for ships on the open ocean.

A study of a dilute effluent (20-25 ppm) in a poorly flushed area clearly showed that even at this concentration the discharge was toxic. Environmental protection standards will have to consider this study or similar evidence when setting future discharge limits. A 20 ppm goal for a high volume oil-water separator appears unrealistic in view of the solubility values of distillate (539 ppm) and NSFO (63 ppm). Even if it were achieved, standards can very well be set lower than 20 ppm.

On-board treatment systems such as oil-water separators are not needed on the open ocean and are not sufficient for in-port needs.

Containment of an in-port oil spill will become more imperative as the Navy switches to distillate fuel. Distillate is more readily incorporated into the water column and can exert a more toxic effect than NSFO due to higher

concentrations. Mechanical containment booms are the
primary means of containing an oil slick.

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CHAPTER FIVE

THE VERTICAL MOVEMENT OF OIL IN SEAWATER
AND THE AGING OF OIL SLICKS

LT Richard S. Peterson

Abstract: Manmade turbulence generated by improper oil spill
control techniques is shown to drive significant amounts of
oil deep into the water column. A simulated fire hose
directed on slicks of three common Navy fuel oils drove oil-
water emulsions to the bottom of a 68 cm deep test tank
within 30 seconds. These emulsions proved stable, as
monitored by a fluorimeter over a period of three days.
    An experiment in vertical molecular diffusion of oil in
seawater produced an upper bound on the diffusion coefficient
of 1.76×10^{-4} cm^2/sec, showing molecular diffusion to be so
slow as to make a negligible contribution to total vertical
oil transport except in areas with highly stratified water
and little vertical turbulence.
    A separate experiment with aging of four Navy oils found
exposure to atmosphere produces selective evaporation of oil
constituents, permitting comparative age dating of slicks
from gas chromatograph traces.

I. INTRODUCTION

The vertical movement of oil in seawater, and its rela-
tionship to equipment and techniques used to control and
clean up oil spills is examined in this chapter. Experiments
were conducted where information was lacking on the vertical
movement of oil. In a separate section, the aging process
of oil slicks, whereby evaporation selectively removes
certain constituents from the oil, is demonstrated. A means
of determining relative ages of oil slicks by comparison of
gas chromatograph traces is given.

As fuels and lubricants, the Navy uses many kinds of oil, which have a wide variety of characteristics [Sigal, 1971]. It was decided to test several oils, in order to determine whether specific spill control was needed for each oil, or whether all oils would respond similarly to control techniques. Oils chosen were selected primarily on the basis of the volume used in the fleet. Navy Special Fuel Oil, or NSFO, is the most widely used oil and was included even though it is now being phased out of use. Navy Distillate, or ND, is the successor to NSFO. JP-5 is the standard shipboard aircraft fuel. Finally, diesel oil was chosen for study because it is used not only by submarines, but by most harbor craft as well. No lubricating oils or greases were tested, first because they are carried aboard in smaller quantities, and second because their piping systems are closed loops that do not have overboard discharges, although small amounts sometimes leak into the bilges.

II. VERTICAL MOTION OF OIL IN SEAWATER

Spreading oil slicks are ugly, and anger many people, but aside from sea birds swimming in the slick, the oil doesn't really harm the marine ecology as long as it stays on the surface of the water column. To photosynthetic algae and other plankton, the slick causes a dimming of light similar to a passing cloud. The slick may also cause a

temporary disruption of oxygen exchange at the surface, but no observed long-term effects. When oil moves vertically, however, it poisons the water with effects reported in Chapter Four, and may even poison the bottom sediments so badly that the former inhabitants cannot return for several years [Blumer et al, 1970]. This section examines various ways in which oil can be transported vertically, and the consequences of this as related to design of oil containment procedures and equipment.

A. MODES OF VERTICAL MOVEMENT

Oil moves vertically in seawater in three basic ways. Listed in order of increasing importance in harbors, they are molecular diffusion, turbulent dispersion, and mechanical mixing. Each of these modes of transport is considered in detail in the paragraphs which follow.

1. Molecular Diffusion

The simplest and slowest form of oil transport is by molecular diffusion. All molecules at temperatures above absolute zero exhibit Brownian Motion, a constant motion in random directions. For this reason, a collection of molecules constantly tend to exchange positions with one another. In the case of an oil film resting on seawater, the oil soon has water molecules mixed in with the oil. Conversely, the water phase soon has a few oil molecules mixed in. These molecules continue to move at random and gradually work their way throughout the body of water in all directions.

Molecular diffusion depends for energy only on the thermal energy of the molecules. It is unaffected by vertical temperature discontinuities which tend to inhibit other forms of mixing. It therefore operates continuously, and may be a significant part of the total oil transport mechanism in strongly stratified harbors not exposed to waves or currents. Molecular diffusion is the only way for oil to dissolve in water. Molecular diffusion is therefore important in moving oil from suspended droplets and slicks into a true aqueous solution. But when the only interface is an oil slick, and without help from water currents, molecular diffusion is an extremely slow process, as shown in the experiment described below.

2. Turbulent Dispersion

Turbulent dispersion considers the motions of parcels of fluid (a continuum, not individual molecules) ranging from the very small, to eddies several kilometers across. Viewed on a scale larger than the circulations of the eddies and averaged over time, the net motion is seen to be zero. By eddy is meant the circulation of the parcel of fluid, involving its mixing into another parcel of fluid.

The smallest eddies are probably those present along any minor temperature discontinuity in a fluid, as groups of water particles having a lower density seek to exchange position with particles having higher density. Larger eddies are formed when wind-driven waves cause particles to circulate in orbits, and non-linear effects provide transport and mixing. Whitecaps and breakers provide particularly

intense turbulence, which may cause the formation of oil-water emulsions, a problem discussed below.

Wind blowing across water or oil tends to drag some of the fluid along with it. When the fluid encounters a boundary, it tends to pile up, and the fluid eventually flows downward along the boundary and back out to its starting point. Depending on the speed of the induced circulation, this may carry dissolved oil or even oil droplets along with the water. This type of circulation occurs not only when the wind encounters a natural boundary such as a shoreline, but also when manmade boundaries are present. Studies have documented the passage of oil under mechanical spill control booms due to such processes [Sorenson and Spencer, 1971].

The passage of large tropical wind systems can cause a large wind setup on shorelines. "Storm surges" may rise 6 feet above normal high tide [Ippen, 1966], and when accompanied with large breakers can emulsify oil and carry it to great distances. Such was apparently the cause of the wide distribution of oil particles found after the grounding of the tanker ARROW [Forrester, 1971], when a survey ship found oil particles at depths of 80 meters at distances of 250 kilometers from the grounding several days after the incident.

Other vertical circulations exist in the open ocean, including the so-called Langmuir circulations. There seems to be no general consensus of opinion on the cause of these flows, but many hypotheses are under study [Scott et al,

1969, Faller, 1969]. Such medium to large scale circulation cells may extend tens of meters in the vertical, and are visible on the surface as "wind slicks" or "windrows" formed where the horizontal portions of the circulations converge [Assaf et al, 1971].

Similar in mechanism to wind-produced circulations, is mixing due to eddies on the boundaries of any moving stream of fluid. The fluid near the boundary is slowed by viscous action. This difference in velocity, or shear, leads to circulations and exchanges of momentum with the interior body of the fluid. Horizontal flows, such as the Gulf Stream, generate eddies on their edges which are often several kilometers across. Similarly, currents flowing along the sea bottom may be expected to produce vertical turbulent eddies on boundary layers at the surface and bottom. From a literature search, it appears the amount of vertical transport of oil and other contaminants by this means has not been investigated.

3. Mechanical Mixing

Manmade turbulence augments the previously discussed methods of oil transport. The absolute amount of oil driven into the water column by such turbulence is unknown, but the experiment in mechanical mixing described below sheds some light on the subject. The importance of manmade turbulence lies in that it is much more intense than circulations produced by most other means. Preliminary experiments to determine absolute oil solubility values in Chapter Four revealed that oil-water emulsions can contain as much as ten times

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the oil that can be dissolved in the same amount of water. Although whitecaps and breaking waves can emulsify oil on exposed coasts and in the open ocean, a sheltered harbor such as San Diego Bay is relatively free of strong turbulence. For this reason the intense turbulence from screws and other mechanical devices represent a potential to put more total oil into the water column by ill-considered "control" procedures than nature would do if undisturbed.

B. THE DIFFUSION-DISPERSION EQUATION APPLIED TO OIL TRANSPORT

Vertical movement of oil, whether dissolved or suspended in an emulsion, can be related to the concentration gradient. That is, in both molecular diffusion and turbulent dispersion the mean flow of oil is from regions of high concentration to regions of low concentration. Since neither dissolved oil nor oil-water emulsions differ significantly in density from the surrounding water mass, the effect of gravity is negligible, leaving the concentration gradient as the only driving force. A mathematical analogy to the diffusion and dispersion of oil is the flow of heat in a solid, for which extensive mathematical treatment has been accomplished [Carslaw and Jaeger, 1959].

The description of vertical oil transport can be further simplified by noting that the horizontal spreading rate as given in the previous chapter is finite, but very rapid compared to the rate at which oil moves vertically. This permits consideration of all gradients in the horizontal as negligible after the initial spread of the oil slick, leaving

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a one-dimensional problem. Since the case considered here does not include oil transport by currents, the mean vertical flow is zero. It is further assumed as an upper boundary condition that the oil phase atop the water is held at a concentration value of 100 percent saturation at all times.

Taking c to represent the concentration of oil in percent saturation at any point, and z the distance measured vertically downward from the surface, the one-dimensional diffusion equation can be stated as

$$\frac{\partial c}{\partial t} = K\frac{\partial^2 c}{\partial z^2} \qquad (1)$$

where K represents a constant to be determined. The boundary and initial conditions are:

1. At the surface the concentration must always equal 1.00.

   $c = 1$, at $z = 0$.

2. For an infinitely deep ocean, concentration approaches zero as depth approaches infinity.

   $c \to 0$, as $z \to \infty$.

3. At the instant the slick appears, concentration is zero at all depths.

   $c = 0$, at $t = 0$.

4. As time proceeds, eventually the concentration at all depths must approach 100 percent, or saturation.

   $c \to 1$, as $t \to \infty$.

A particular solution to equation (1) satisfying the initial and boundary conditions is [Carslaw and Jaeger, 1959]

$$c = 1 - \text{erf} \frac{z}{2\sqrt{Kt}} \qquad (2)$$

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with the error function given by

$$erf(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{-v^2} dv \qquad (3)$$

The coefficient K in equation (2) corresponds to either a molecular diffusion coefficient or a turbulent dispersion coefficient and is determined experimentally.

Solutions (2) and (3) meet the initial and boundary conditions and are thus the desired particular solution. Since the equations are written only in terms of time, depth, concentration, and coefficient K, all effects of temperature, viscosity, and speed and scale of eddies are incorporated into the value of K. A comparison of the experimental results for the molecular diffusion experiment to the theoretical concentration versus depth relationship is discussed in a later section.

C. MOLECULAR DIFFUSION EXPERIMENT

An experiment was performed to determine the coefficient of diffusion for the molecular diffusion of Navy Distillate fuel oil into seawater. In sheltered harbors with small tidal currents and stratified water, molecular diffusion may represent a significant part of the total oil transport process.

1. Molecular Diffusion Apparatus

A glass column 2.2 meters high and 78 mm in diameter with sampling ports spaced along its length was constructed as shown in Figure 5-1. The column was filled with filtered

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Molecular Diffusion
Apparatus
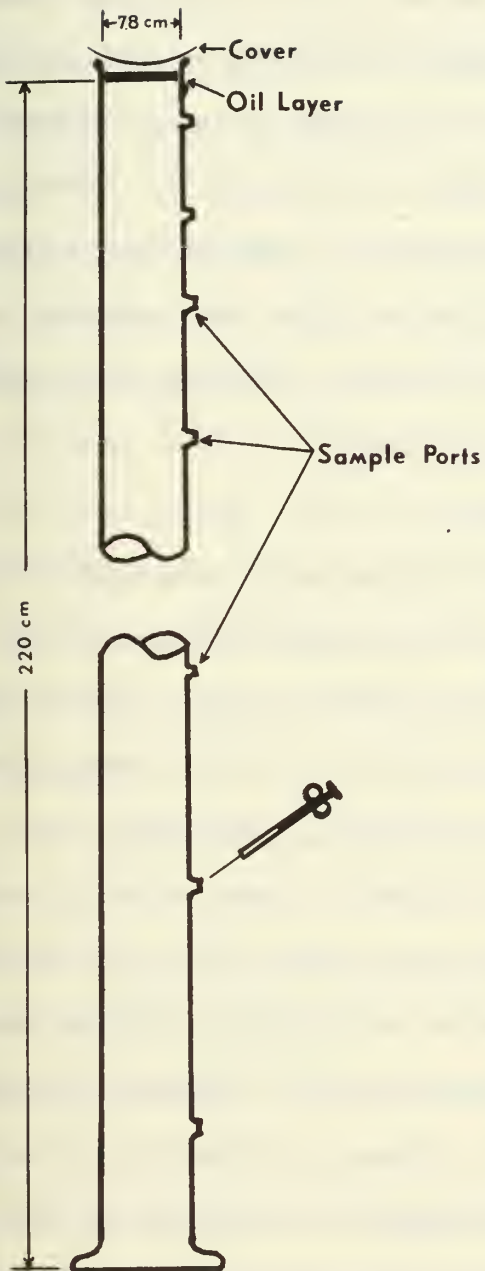
Sample Port Depth Spacing	
port	depth (cm)
1	5
2	10
3	15
4	25
5	35
6	50
7	75
8	100
9	125
10	150
11	175
12	200

Figure 5-1. Molecular Diffusion Apparatus.

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seawater, wrapped with insulation, and then permitted to stand several days to allow thermal currents to subside.

A fluorimeter as described in Appendix C was selected to measure concentrations of the oil as it diffused downward along the column. For comparison, standard solutions of known concentration were made by filling a large beaker with seawater and adding 2 cm of oil to the surface. The contents were stirred gently each day, so as to prevent emulsification, and after two weeks the water phase was assumed to be saturated with oil. Dilutions of this saturated solution were used to calibrate the fluorimeter.

2. Experimental Procedure

The molecular diffusion experiment was begun by carefully pipetting 100 ml of Navy Distillate onto the surface of the water at the top of the column. The column was then covered with a watch glass to control evaporation.

Samples were taken hourly at first, then less often, with the final set of samples taken 15 days after commencement. Complete data are available in the files of the Navy Pollution Study Group at Monterey. It soon appeared that the volume of water taken for each set of samples excessively lowered the water level of the column and had to be replaced after each run. Initial replacements were made at the top of the column, until it became obvious that this caused mixing. After this, replacement water was added through the bottom sample port and no further evidence of mixing appeared.

3. Molecular Diffusion Results

Figure 5-2 shows concentration of oil versus depth at various times throughout the experiment. Note the early well-mixed layer due to water replacement at the top of the column, and the final concentration profile approaching an exponential decay curve in its lower portion.

Based on the set of 15-day samples, an upper bound figure for the coefficient of molecular diffusion of Navy Distillate into seawater at 20°C is 1.76×10^{-4} cm^2/sec. This coefficient represents an extremely slow rate of transport, since no oil was detected even 35 cm deep after 15 days. Molecular diffusion, then, may be assumed not to introduce significant quantities of oil into the water column, and oil spills in conditions under which it is the dominant mode of vertical oil transport are relatively harmless to the marine environment, providing the slick is removed in a reasonable time.

4. Magnitude of Diffusion Equation Coefficients

In general, horizontal diffusion equation coefficients are much larger than those for vertical transport. Bowden [1962] attributes this to the larger horizontal than vertical extent of most bodies of water, and to stratification by temperature layers which are usually present. Turbulent diffusion coefficients normally range from 1 to 10^3 cm^2/sec for vertical movement and from 10^5 to 10^8 cm^2/sec for the horizontal. In comparison to turbulent dispersion coefficients, those for molecular diffusion are extremely small.

Molecular Diffusion Results
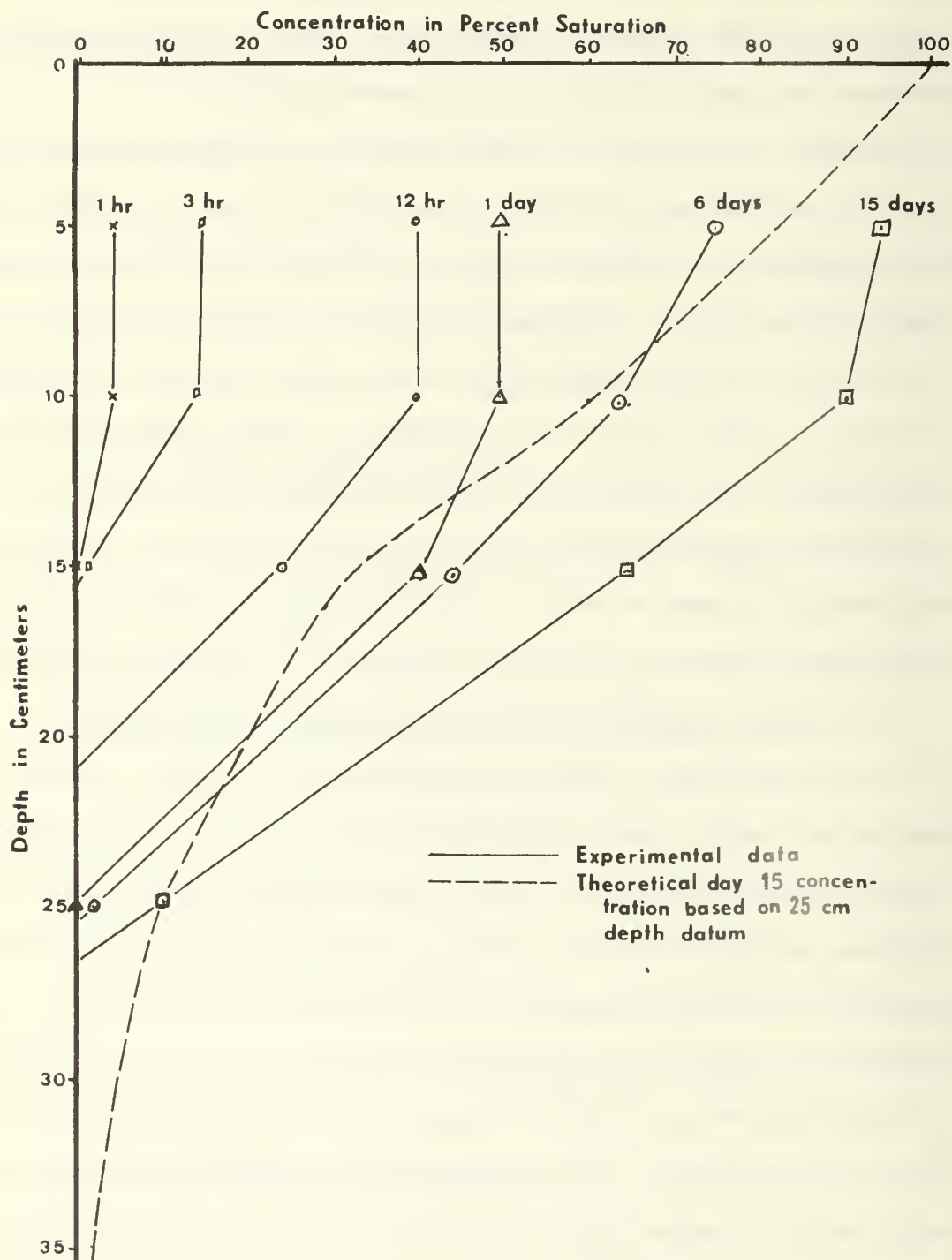
Figure 5-2.   Molecular Diffusion Results.

D. MECHANICAL MIXING EXPERIMENT

Natural turbulent circulation can occur on many scales,
as discussed earlier. In most cases, however, nature's
turbulent circulations are relatively slow. Although
turbulence may move tremendous masses of material, as
exemplified in Gulf Stream eddies, it is usually not violent
enough to form emulsions of oil and water. The notable
exceptions to this, breaking waves and whitecaps, can and
do form emulsions, but these are not normally encountered
in sheltered harbors. Man, on the other hand, produces
turbulence which is commonly of small size, but very intense.

1. Relationship to Operational Situations

A common Navy practice in reaction to the sight of
a relatively small oil slick is to immediately call out a
detail with fire hoses to control the oil and keep it from
spreading. Indeed, sometimes the oil slick is small enough
so that a few minutes of direct fire hose spray result in
the disappearance of the slick--the problem is "solved."
Large oil spills sometimes present the picture of small
craft running back and forth through the slick, supposedly
picking up oil but in the process churning much into
emulsions with their screws. Some oil control devices
inherently produce turbulence as a result of their design.
Hydraulic booms, for example, "control" oil with bubbles.
The dynamic plane which is designed to be towed over a slick,
forcing it below the surface then allowing oil to float up
into a collection chamber, is another example of a device

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which, by its nature, must induce turbulence. The amount of this turbulence and its relationship to emulsion formation is not mentioned in the design study [March, 1970].

In the mechanical mixing experiment described below, turbulence was induced in oil slicks to simulate the effect of using a fire hose as a control device. The objective of the experiment was to determine the amount of oil driven underwater by using this procedure.

2. Mechanical Mixing Apparatus

A 3/4-inch diameter garden hose with an adjustable nozzle was used to simulate a Navy fire hose being used to control oil slick movement. Referring to Figure 5-3, the hose was fixed so as to direct its stream into the center of the surface of the test tank. A sample tube was led from the bottom of the test tank and operated as a siphon during the experiment; all samples were taken from the lowest part of the test tank, a depth of 68 cm below the surface at the beginning of the experiment.

With the nozzle set to produce the maximum straight stream with minimum side spray, the stream exit velocity was 11.2 m/sec, with a delivery rate of 660 liters/hr. This stream drove bubbles 22 cm down into the test tank when there was no oil present. A standard Navy 1½-inch fire hose delivers a nominal 14400 liters/hr of water. If the fire hose stream carries to distances of 120 feet, a reasonable figure, the exit velocity would be 19.0 m/sec. Comparing the two streams, the test stream is seen to have about 57 times less kinetic energy than the fire hose.

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Mechanical Mixing Apparatus
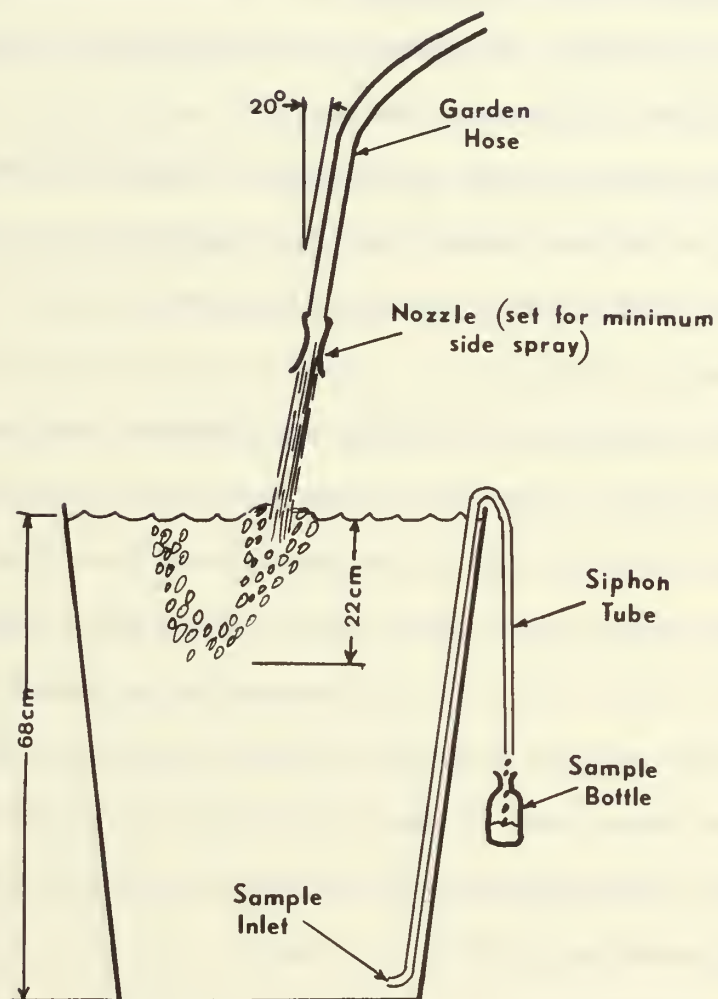
Figure 5-3.   Mechanical Mixing Apparatus.

3. Experimental Procedure

The tank was filled and allowed to stand 15 minutes
to permit strong circulations to subside. Siphoning was
then begun on the sampling tube and 100 ml of the test oil
pipetted onto the water surface. A sample was taken from
the bottom of the tank at this time to ensure there was no
oil remaining from previous runs. The hose was then charged
and samples taken at 15 seconds, 30 seconds, 1 minute, and
2 minutes after agitation had begun.

Samples were allowed to stand in stoppered test tubes
until they could be tested on the fluorimeter. Due to other
experiments in progress on the fluorimeter this time varied
from ½ hour to 3 days.

It was originally intended to compare the sample fluori-
meter traces with those from the standard solutions used in
the molecular diffusion experiment, and thus obtain quanti-
tative values for the amount of oil present. This proved
impossible, since the oil in the mixing experiments was held
in suspension rather than dissolved in water. The fluori-
meter trace therefore showed the effect of a different
solvent (see Appendix C) and absolute quantitative measure-
ments could not be made.[1]

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[1]As a suggestion for future investigators, a fairly large
sample (about 2 liters) of an oil-water emulsion could be
prepared by shaking. After allowing the emulsion to stand,
and decanting to remove any droplets or slick, part of the
emulsion could be subjected to an ether extraction process
to determine the absolute amount of oil present. The rest
of the sample would be used to make serial dilutions to
calibrate the fluorimeter.

4. Mechanical Mixing Results and Conclusions

Although no estimate of absolute amounts of oil present could be made, all tests showed the same sequence of results. The sample taken at zero time showed no oil, while the sample after 15 seconds agitation showed traces. Samples of all runs after 30 seconds of agitation showed definite oil present at the bottom of the tank, and the amount increased rapidly for samples taken later.

It is significant that such a small test stream, possessing almost 60 times less energy than a fire hose, caused the formation of emulsions which were swept to the bottom of the tank, 68 cm, in 30 seconds or less. This was true for all oils tested; Navy Distillate (ND), JP-5, and diesel. Re-runs on the fluorimeter showed that the oil still remained in suspension three days after the test, making it evident that the emulsion would behave as part of the water mass and could be expected to be carried wide and deep into the water column by turbulent dispersion.

Suspensions like this are very susceptible to ingestion by marine organisms, particularly filter feeders such as clams, oysters, etc., and could produce toxic effects as noted in the previous chapter. It is possible that suspended oil particles might prove even more toxic to life than dissolved oil, as the suspended particles are representative of the entire oil, while the dissolved molecules are only those which have relatively high water solubility constants.

Based on the results of this experiment, it is recommended that the practice of herding oil slicks by fire hose

be discontinued. Furthermore, any cleanup or control device which generates turbulence should be checked for emulsion formation potential.

III. AGING OF OIL SLICKS FROM EXPOSURE TO AIR

A. ECONOMIC AND LEGAL PROBLEMS

The primary reason for trying to determine responsibility for an oil spill is to find out where to send the cleanup bill. New laws add the question of who, if anyone, has legal liability. Aside from vessels "caught in the act" the primary means of determining guilt is by analysis of the oil slick. Tests include chemical analysis, use of fluorimetry, and chromatographic techniques, and the progress in this field is heralded by oil industry publications nearly every month.

Navy fuel oils differ significantly in composition from the crude oils and less refined oils commonly carried by tankers and used by merchant ships for fuel [Boylan and Tripp, 1971]. For this reason they are readily identifiable as Navy fuels. Unfortunately for the Navy however, since large numbers of ships get their fuel from a single source, no further pinpointing is possible. From the civilian's point of view, it doesn't really matter. As far as he is concerned the Navy is at fault and he doesn't care who spilled the oil, as long as it is quickly cleaned up and doesn't happen again.

The economic problem relating to identification of oil slicks is primarily a Navy one. In San Diego and elsewhere, a civilian contractor is hired to do spill cleanup work. The contractor assumes responsibility for complete cleanup of the oil, and is paid accordingly. In several cases in San Diego, it has happened that a few hours after an oil slick was removed from the bay, it reappeared. The question immediately arises whether such a slick is the result of a new spill, or whether it is a remnant of the old slick, perhaps held under some piers by San Diego's swift tidal currents. Since payment of the contractor depends on the answer, and since payment may amount to several thousand dollars for a widespread slick, the correct answer is important. The purpose of this section is to propose a simple, scientific solution to the problem.

B. OIL SLICK AGING EXPERIMENT

An oil slick remnant from a previous cleanup operation may have been swept under a pier by wind or current, or may have temporarily coated a beach or even have been carried out to sea. In any case, it has one main difference from a new slick--the remnant has been exposed to contact with the atmosphere for a longer time, usually on the order of several hours. Navy oils are a mixture of a large number of different types of molecules. Each of these molecules has its own peculiar characteristics, including its tendency to evaporate into the atmosphere. This is the basis of age-dating oil slicks.

1. Experimental Apparatus

Oil slicks were created in the laboratory for each of the four fuels studied; ND, NSFO, JP-5, and Diesel. Standard test slicks were prepared by filling an enameled steel pan 10 cm deep with filtered seawater, then pipetting enough oil onto the surface to make a slick 1 mm thick. Pans were 42 cm by 28 cm in size, and were kept on a table in the laboratory near a north-facing window so that no direct sunlight fell on the standard test slicks. Room temperature was maintained at 18°C to 22°C.

Because operational oil spills encounter a wide range of conditions, additional slicks of Navy Distillate were set up to examine the effects of other parameters. Two slicks were placed on the roof of the highest campus building, one in the sun, the other shaded but exposed to wind. This aging experiment was terminated after four days by a storm accompanied by 70 knot winds which blew the pans from the roof. Another slick was prepared in a closed bottle which was arranged to permit a constant flow of fresh seawater under the slick, but minimized exposure to air. An example of this situation might obtain for oil coating a piling. Finally, a slick 1 mm thick (compared to 1mm for the standard) was prepared to test the effect of an increased ratio of volume to surface area.

The effects of temperature on oil slick aging were not investigated. Presumably, higher temperatures would speed evaporation and hence aging, while lower temperatures would

retard the process. Future investigations are needed to determine the significance of this effect in relation to application of the Navy procedure recommended below. Cold water harbors may find the process to be too slow for relative age determinations.

2. Sampling Procedures

Slicks were sampled when they had been exposed to the air for ½, 1, 2, 4, 6, 12, and 24 hours, and daily thereafter for a total of 12 days. An eyedropper was used to pick up a small portion of the slick and transfer it to a test tube. The test tube was allowed to stand a few minutes to permit the oil and water to separate, then a 0.0003 ml sample of oil was injected into a gas chromatograph by use of a Hamilton microliter syringe. Details of the principles of operation and model specifications for the chromatograph used are contained in Appendix C. A temperature program of 70°C to 305°C at 10°C/minute was used for all tests in this series. Analysis of relative heights of selected peaks, and the original chromatograph traces are on file with the Navy Pollution Study Group in Monterey.

3. Results of Standard Aging Experiment

Figures 5-4 through 5-7 show the gas chromatograms for Navy Distillate, NSFO, JP-5, and diesel fuel. In each case the original trace is shown, with traces for 24 hours and for 12 days of aging superimposed thereon. It is clear that the lighter, or lower-boiling constituents of the oil have disappeared, presumably by evaporation. Measurement of relative heights of numbered peaks shows a decline in
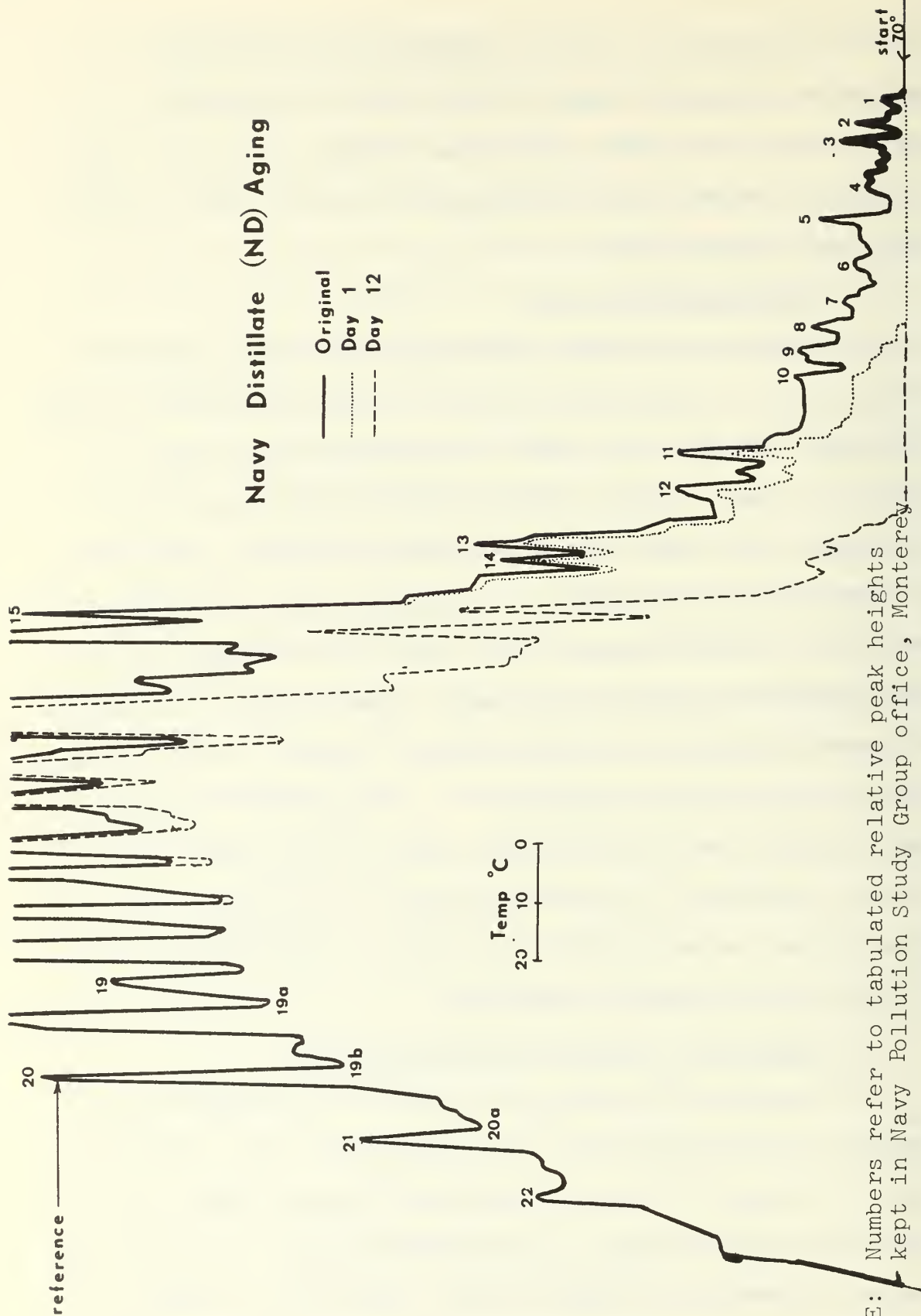
Figure 5-4. Navy Distillate (ND) Aging.

NOTE: Numbers refer to tabulated relative peak heights kept in Navy Pollution Study Group office, Monterey.

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NOTE: Numbers refer to tabu-
lated relative peak
heights kept in Navy
Pollution Study Group
office, Monterey.

Figure 5-5. NSFO Aging.

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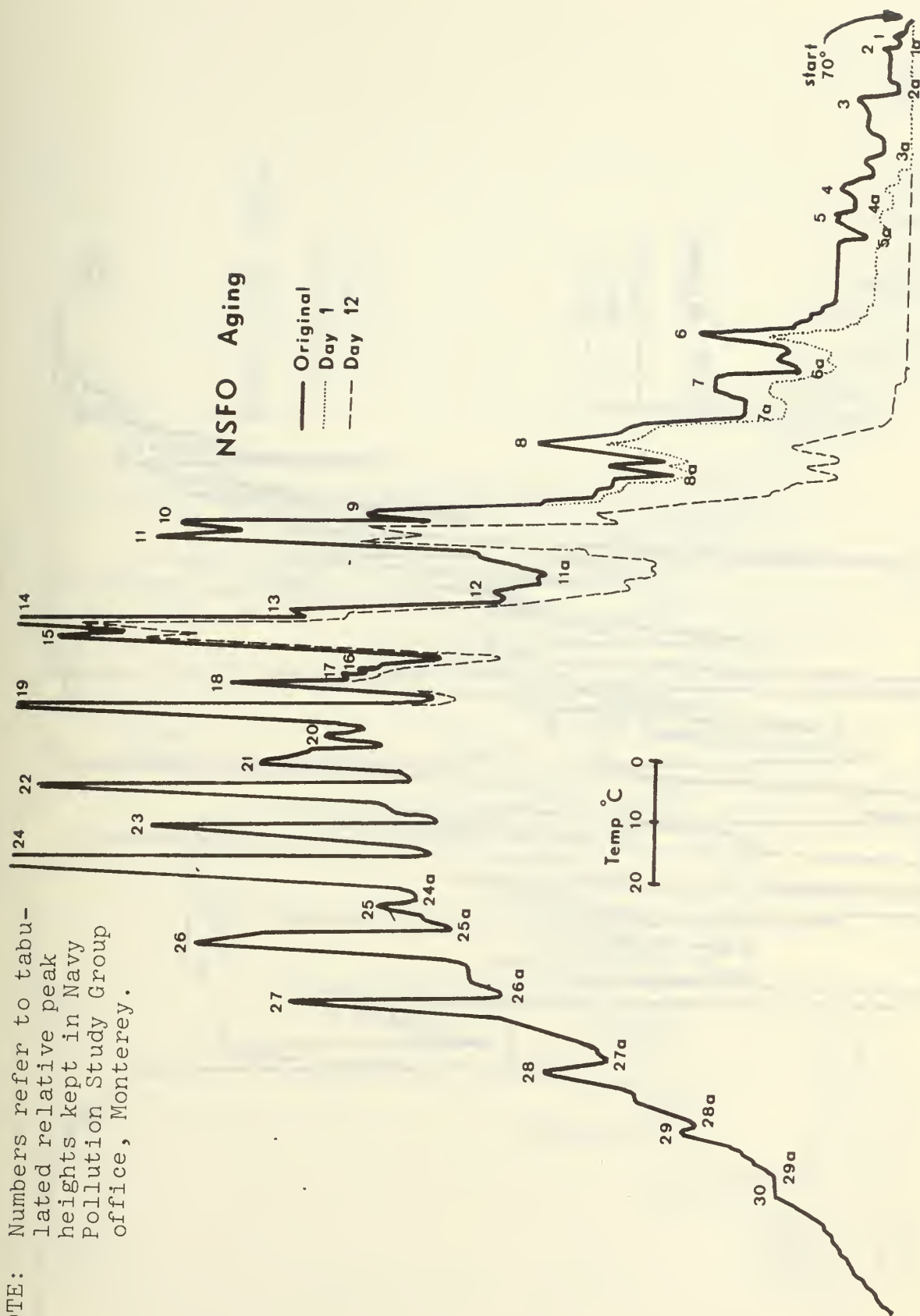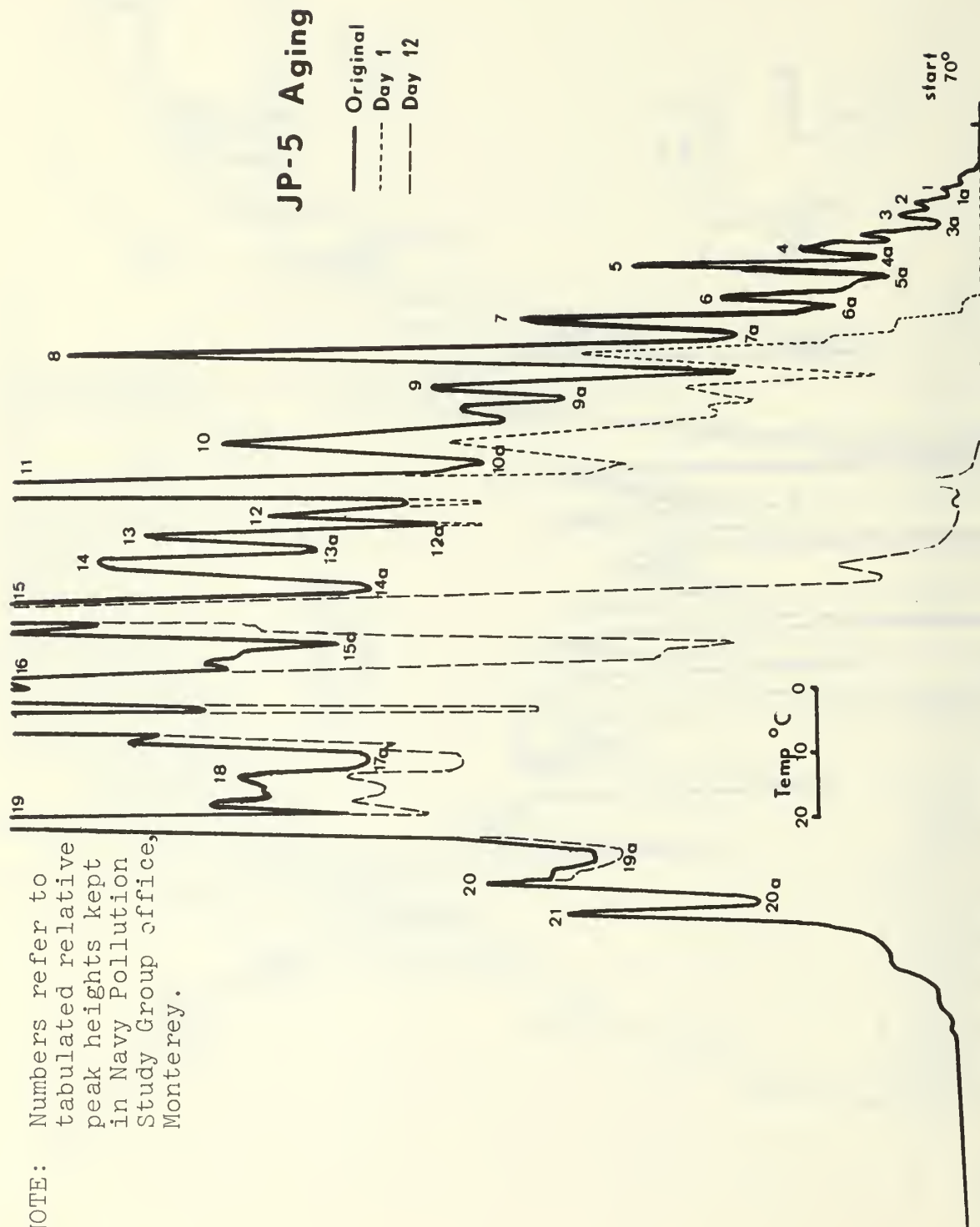
Figure 5-6. JP-5 Aging.

NOTE: Numbers refer to tabulated relative peak heights kept in Navy Pollution Study Group office, Monterey.
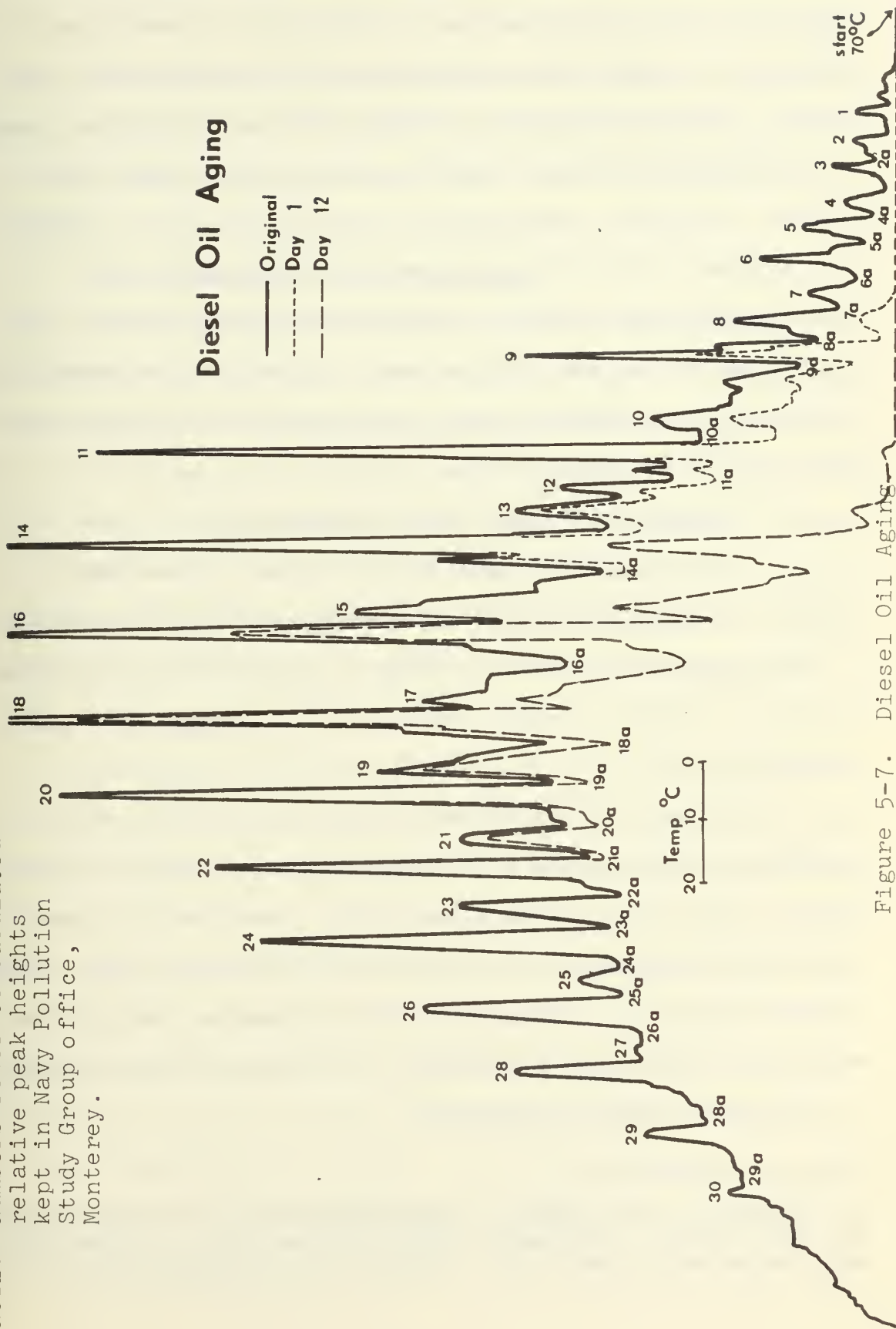
Figure 5-7. Diesel Oil Aging

NOTE: Numbers refer to tabulated
relative peak heights
kept in Navy Pollution
Study Group office,
Monterey.

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amplitude of all low-boiling peaks, with the decline most rapid for the lowest boiling. This change in relative amounts of constituents with time will be referred to as aging. Neither the rate of decline for an individual peak, nor the relative rate of decline between two peaks was smooth. However, although the absolute height of a peak for a given amount of aging was not predictable, the decline was ever-present; aging never increased the height of a peak on the low-boiling end. In addition it should be noted that the chromatograms for the four different fuels are readily distinguishable.

4. Influence of other tested parameters

The oil slick exposed to the sun for four days showed a barely detectable acceleration of aging relative to the standard slick kept indoors. The slick kept in the shade but exposed to winds showed no difference from the standard slick.

In contrast to the minimal effects of sun and wind, thickness of slick was a definite factor in rate of aging. After 12 days, the 10 mm thick slick showed only as much aging as the standard slick had experienced in 2 days. Thus, if an oil slick is confined by some boundary, the physical effects of the aging process will be slowed drastically due to increased slick thickness.[2]

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[2]Effects of biological degradation have not been induced in this study. Increased slick thickness may increase rate of biological attack. See Chapter Six, Section I-D.

Finally, the slicks which were exposed to unlimited running seawater but denied access to air failed to age at all. After 12 days of exposure, the two slicks so tested (one each of ND and NSFO) produced chromatograms similar to those of the control slick only ½ hour after exposure to air.

5. Discussion and Recommendations

Despite the fact that oil spills in operational circumstances are subjected to a wide variety of environmental conditions, and although it is not possible to predict the exact shape of a chromatogram in advance, this technique still can serve its purpose. The use of gas chromatography is sufficiently sensitive and reliable to determine whether or not a slick is a remnant of a former incomplete cleanup operation. It thus can be used as a basis for adjudging contractor payment.

It is suggested that whenever a contractor is called to deal with an oil spill, the senior Navy liason officer take a small sample from the slick. Only a few drops are needed, and may be kept in any stoppered container; a pill vial is ideal. After cleanup is complete, if no new slick appears for 24 hours the sample may be discarded. If a new slick appears which is possibly a remnant of the former spill, a new sample should be taken, and the two samples subjected to gas chromatograph analysis. It is not necessary that the time/temperature program employed in this study be used; any available program will suffice. If the new slick is of the

same type oil and has aged more than the old slick; that is, if the new slick shows lower peaks on the first traces to come out of the chromatograph, the new slick should be considered to be a remnant of the old. The same aging, or less for the new slick, or a different oil type, indicates an independent spill, for which the contractor must be paid separately.

IV. CONCLUSIONS

The intensity of manmade turbulence produced during oil spill control and cleanup operations may exceed that of natural turbulence in sheltered harbors, causing a greater amount of oil to be forced into the water column. Of the natural turbulence-causing mechanisms, only whitecaps and breaking waves normally possess sufficient intensity to form stable oil-water emulsions, and these are not normally found in harbors. The experiments reported here have shown, on the other hand, that a simulated fire hose used to control slick spread, readily forms such emulsions, and that they are readily distributed vertically throughout the water. Emulsion formation by screws of cleanup vessels, hydraulic control booms, and other control devices was not investigated due to time limitations, but should be considered before widespread use is made of any cleanup device.

Rather than trying to immediately "herd" an oil slick with fire hoses until a boom can be deployed, the oil can

be allowed to flow over stratified water such as is often present in harbors. In this case, molecular diffusion may be the primary vertical transport mechanism, and an experiment found that this process is so slow as to be negligible. In many cases, smaller amounts of toxic oil would be dispersed throughout the water by allowing the slick to spread until gentle control measures were available, than by immediately attacking on all fronts as is commonly done. The use of non-turbulence-causing aids such as molecular monolayers (Shell's Oil Herder for example) should be more fully investigated for this purpose.

A method for obtaining relative ages of oil slicks by use of gas chromatograph analysis was shown to be a reliable indicator of whether an oil slick is the result of a new spill or whether it is a remnant of an earlier incident. Selective evaporation of certain constituents of the oils provides an estimate of the time each slick has been exposed to the atmosphere, and indicates relative ages for the slicks even though a number of factors prevent prediction of the absolute ratios of constituents to be expected at a given time.

V. ACKNOWLEDGMENTS

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CHAPTER SIX

CHARACTERIZATION AND TREATMENT
OF BILGE AND BALLAST WATER

LT Clancy J. Hatleberg

Abstract: The problem of controlling oil pollution derived
from the discharge of bilge water by U.S. Navy ships was
investigated. Samples of bilge water were obtained for
analysis from ships in the San Diego and Long Beach Harbors.
Oil in bilge water was found to range in concentration from
100 ppm to 100% and to be of the same type as found in
the piping system of the spaces above the bilges. Bilge
water at all depths contained oil concentrations in excess
of Navy oil pollution standards. A listing of currently
available means of separating oil from water was compiled.
Biological degradation, bilge ballast transfer and the
harbor donut were proposed as temporary solutions for con-
trolling pollution from bilge water.

I. BILGE WATER ANALYSIS

Bilge water is the result of the collection of oil and
water from leakages and spills in a ship's lubricating,
hydraulic, fuel and water systems into the bottom-most
decking of the engineering spaces. Little is actually known
about the distribution of oils present in bilge water or
their concentrations; therefore, samples of bilge water were
collected to determine the nature of, and realistic param-
eters for the pollution due to bilge water discharge.

A. SAMPLING PROGRAM

A tour of Navy ships in the San Diego and Long Beach
Harbors was conducted during the period of 7 to 9 November

1971 to collect bilge samples. Sixty-three samples were obtained from ten different ships, of which half used Navy Distillate for fuel; the other half used diesel fuel. Ships using Navy Special Fuel Oil (NSFO) were not sampled because they will all be converted to Navy Distillate by the end of fiscal year 1973. The San Diego and Long Beach sample of ten ships represented the total number of ships that used either Navy Distillate or diesel fuel. Samples were taken from every bilge that contained some liquids--several pump room and shaft alley bilges were dry. Samples were taken with a clean 10 ml pipette and placed in a clean test tube for transfer and handling. Where possible, samples were taken over a range of depths in each bilge to obtain concentration gradients.

B. OIL IDENTIFICATION

Recently there has been much discussion and research in the area of determining an identification scheme or "finger-print" for petroleum products. With these "fingerprints" it would be possible to analyse an oil spill and determine its origin. Several methods are now being explored to determine identifying characteristics of petroleum products; among these are fluorescence, gas chromatography, trace metal analysis and infrared spectrometry. The method of fluorescence and gas chromatography are discussed in Appendix C.

Trace metal analysis establishes the ratio of trace metals present in a petroleum product. These ratios are unique for oils from different geographic locations. A

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tabulation of trace metal content for petroleum products could then be used for comparison with oil samples from a spill.

The technique of infrared internal reflection spectrometry can be used to establish oil "fingerprints" by cataloging transmission infrared spectra. These characteristic spectra can be recorded in a library of infrared "fingerprints" for use in identifying oil spills. Any such library of oil "fingerprints" must also include the effects of weathering of the oil by exposure and biological degradation (see Chapter Five, Section III).

C. PROCEDURES AND EQUIPMENT

The Bendix 2200 gas chromatograph was used to identify the type of oil in each bilge sample. Chromatograph parameters are listed below.

detector	flame ionization
column	1/8"-8' 20% SE 30 chromsorb W
detector temperature	150° C
injection temperature	200° C
carrier gas	helium
flow rate	50 cc/min
recorder attenuation	500 to 100
input attenuation	X10
suppression	X10 K
temperature program	70° C to 300° C @ 10°/min
recorder rate	1/2 in per minute

In order to identify the type of oil present in a bilge sample it is necessary to note the time of occurrence of each peak on the chromatograph record and also the relative time between peaks. A comparison can then be made with a known sample.

A triple-pass ether extraction was performed to determine the concentration of oil present in each sample. Control ether extractions using a known quantity of oil resulted in recovery within 1.4% of the original weight.

D. DISCUSSION OF RESULTS

Identification of oil in bilge samples was complicated by the possible processes of biological degradation, extraction by water layers, dilution by other oils and aging. The oil in many samples had been degraded to such an extent that identification by gas chromatography was made all but impossible. Sample number one from San Diego was taken from the surface of a fire room bilge. Gas chromatography at a recorder attenuation of 100 revealed a well developed profile which is clearly identifiable as Navy Distillate (Figure 6-1). Sample number two from San Diego was taken just four inches below sample number one. Gas chromatography at the same attenuation reveals a less well defined profile as seen in Figure 6-2. Analysis by ether extraction resulted in similar concentrations of 18,290 ppm for sample one and 10,850 ppm for sample two.

Analysis by ether extraction will not reflect the amount of oil removed by the various processes. Most samples contained colloidal filth and debris which was lost during extraction and was not reflected in the results. All samples were taken during quiescent water conditions so that gravity separation had taken place.
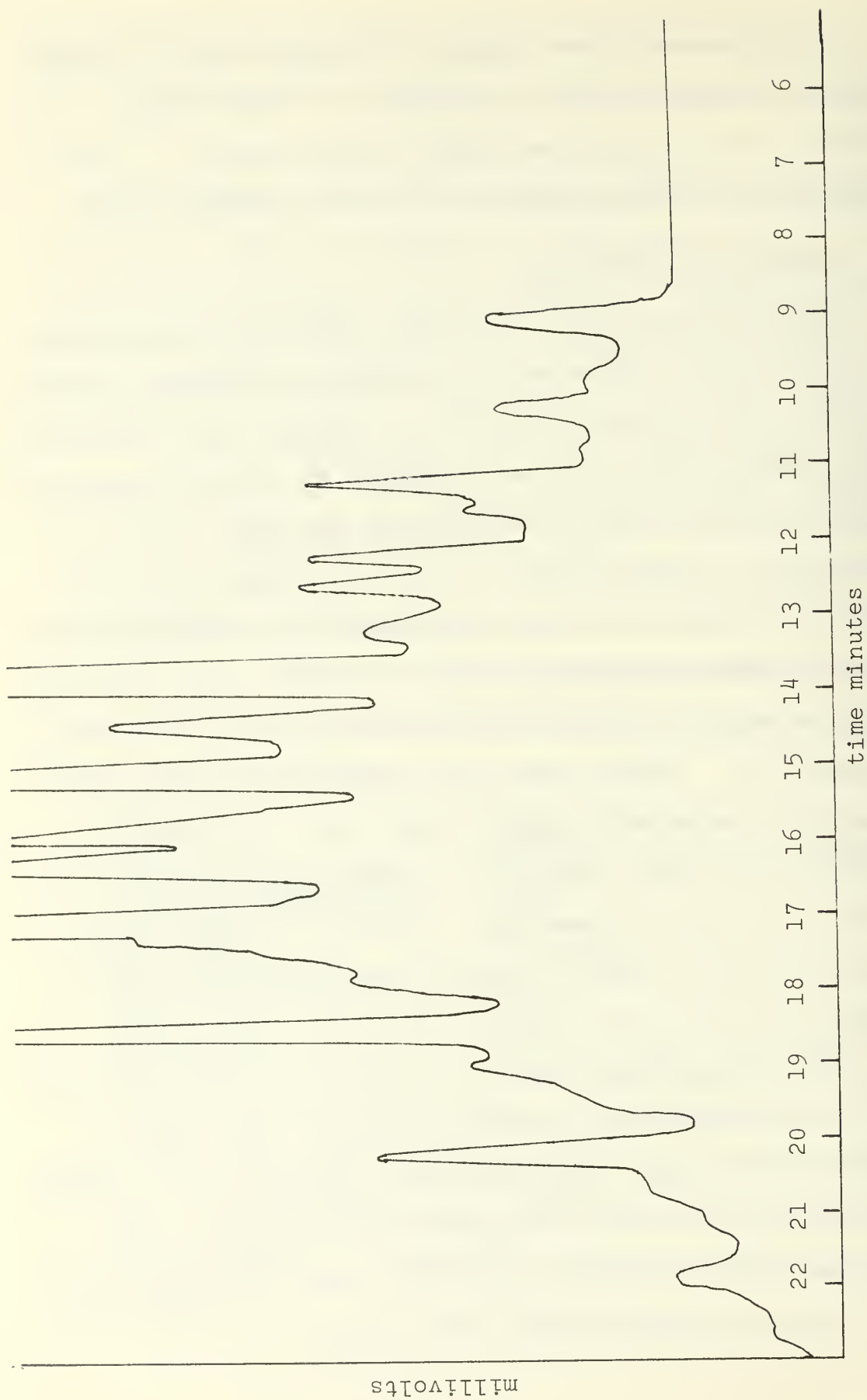
Figure 6-1. San Diego Sample #1.
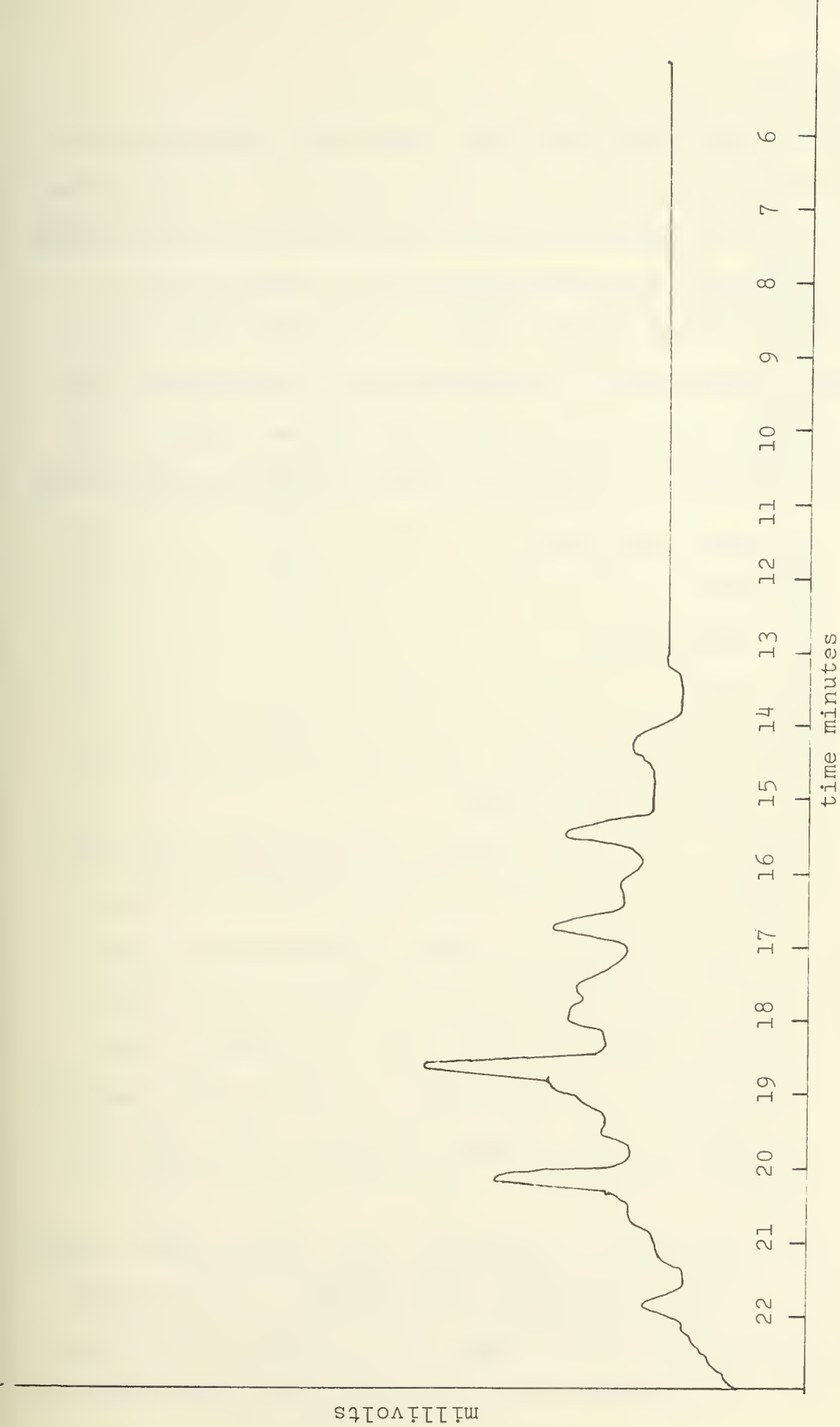
Figure 6-2. San Diego Sample #2.

time minutes

millivolts

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Bilge sample profiles were compared to the profiles of
Navy Distillate, NSFO, diesel fuel and JP-5. Oil was found
present in all bilges sampled except in one pump room bilge.
Oil was found in the form of emulsions, solutions and
physically differentiable layers. Colloidal filth in
suspension was found in the majority of the samples. Oil
in the bilges was generally the same type as found in the
piping system in that space and was identified primarily as:

- Navy Distillate
- NSFO
- diesel fuel
- JP-5

In addition, solvents, paint, rust and heavy lubricating
oils were found in some bilges.

Generally, the surface waters of the bilge contain the
highest concentration of oil. In many cases the middle
layers of the bilge had the lowest concentrations of oil
with the bottom layers having an increased concentration
over the middle layers but less than the surface layers.
The probable reason for this type of concentration gradient
is the presence of oily sediment layers on the bottom of
the bilges.

Figure 6-3 gives a breakdown of the concentration ranges
found in the bilge samples. Just over 50% of the samples
had concentrations in the range of 1,000 ppm to 20,000 ppm,
while 75% of the samples had concentrations in the range of
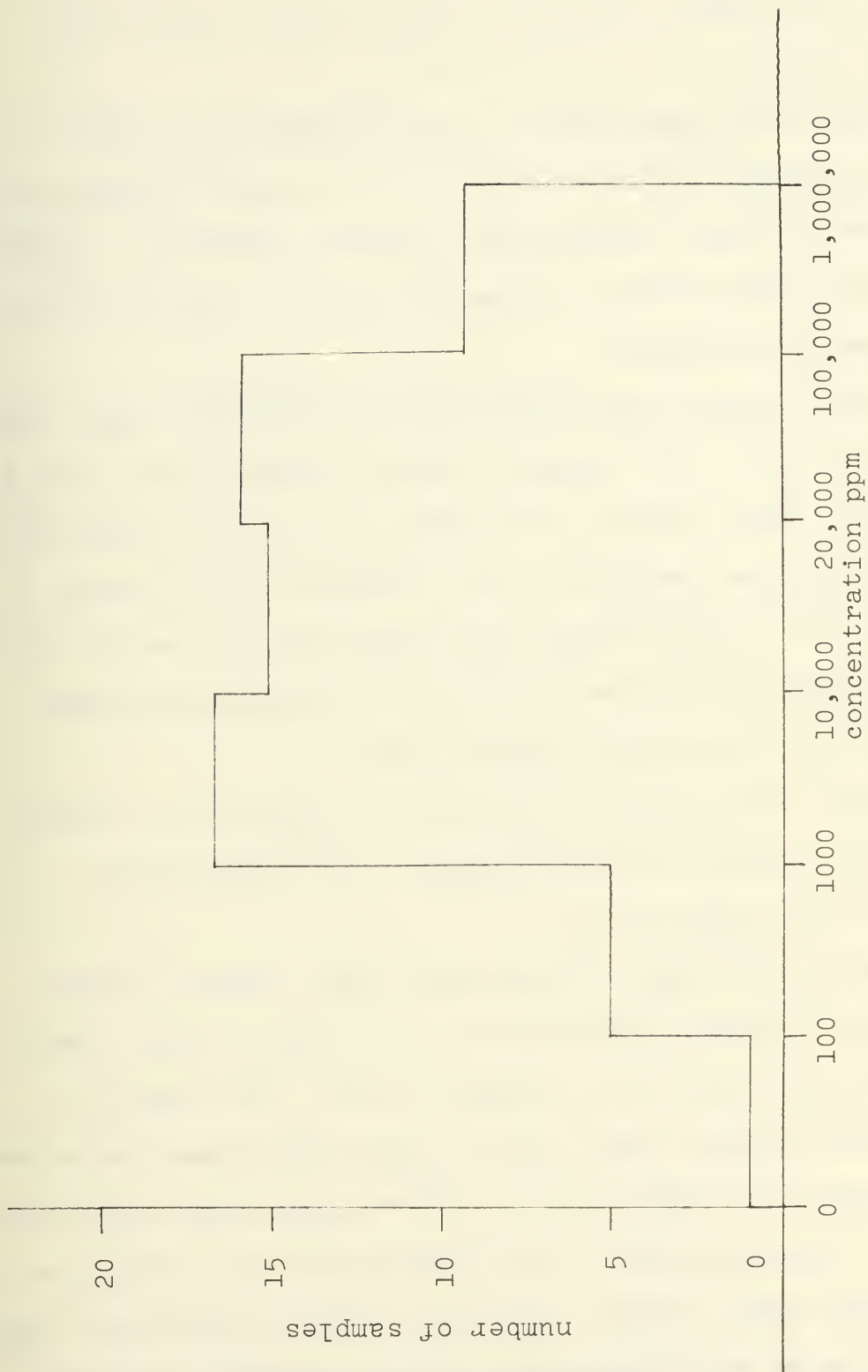
Figure 6-3. Concentration Ranges.

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1,000 ppm to 100,000 ppm. All samples with concentrations of oil in excess of 100,000 ppm were taken from diesel engine rooms.

Fire room bilges had oil concentrations from 417 ppm to 23,878 ppm and declining gradients with depth (Figure 6-4). Fire room bilges contained the greatest amounts of filth, paint and other debris. Fire room samples were the least well resolved samples.

Diesel engine room bilges had the highest concentrations of oil of any of the samples tested, ranging from 9,943 ppm to 100%. They also had "V" shaped concentration gradients indicating the presence of oily sediment on the bottom (Figure 6-5). Navy distillate engine room bilges had concentrations of oil from 373 ppm to 75,335 ppm and mixed concentration gradients (Figure 6-6).

Shaft alley bilges contained an emulsion of oil and water in a range of concentrations from 9,088 ppm to 180,853 ppm (Figure 6-7).

Pump room bilges were generally the cleanest bilges sampled. The pump room bilges on the diesel ships were exceptionally clean with respect to oil. The range of concentrations was from 0 ppm to 100% with mixed concentration gradients (Figure 6-8). The two pump rooms with the highest concentrations of oil had experienced casualties to their piping systems. Analysis of the experimental data clearly shows that bilge water at all depths in a bilge contains oil concentrations in excess of Navy oil pollution
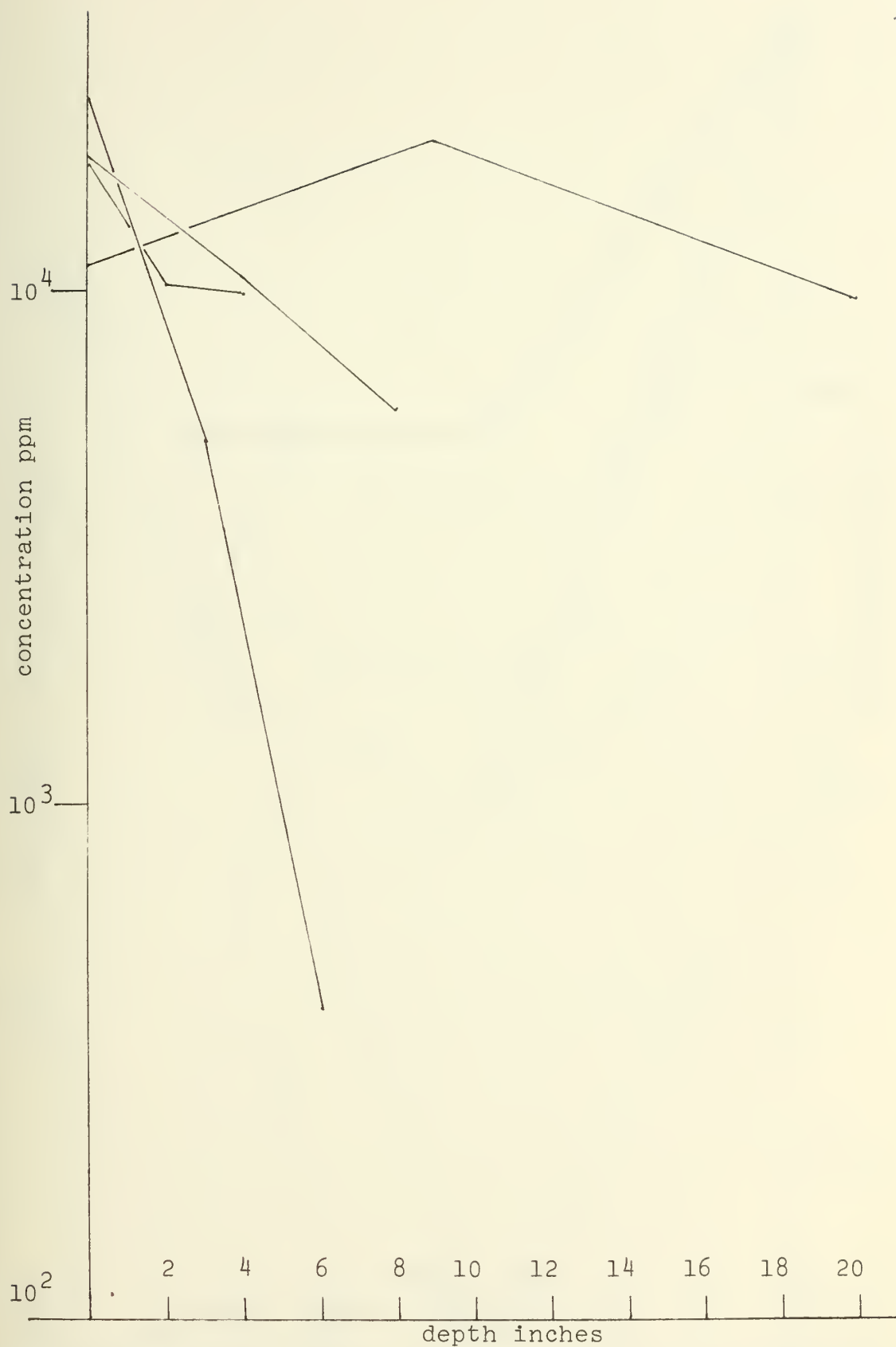
Figure 6-4.   Oil Concentration vs Depth in Fire Room Bilges.
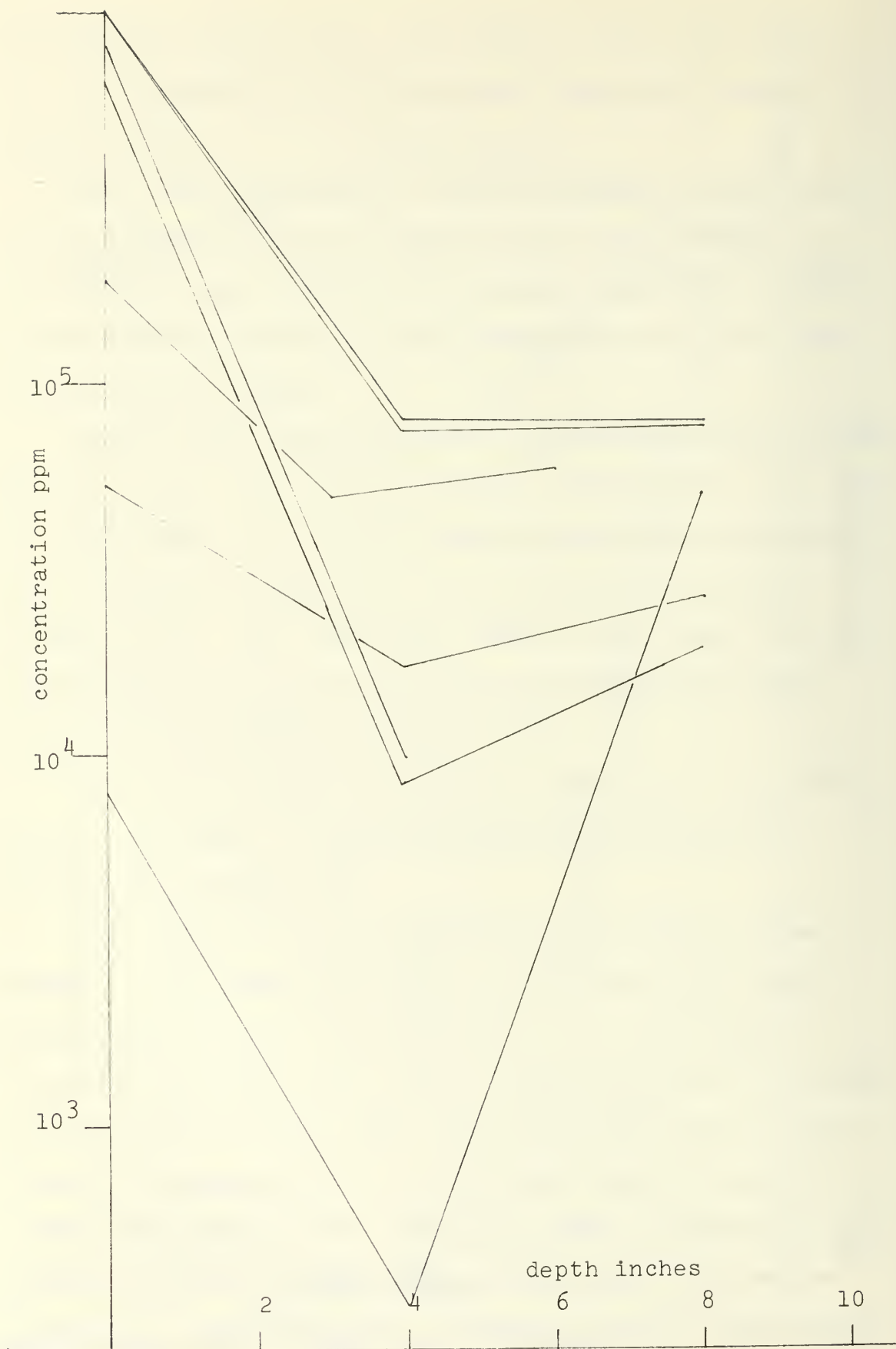
Figure 6-5. Oil Concentration vs Depth in
Diesel Engine Room Bilges.
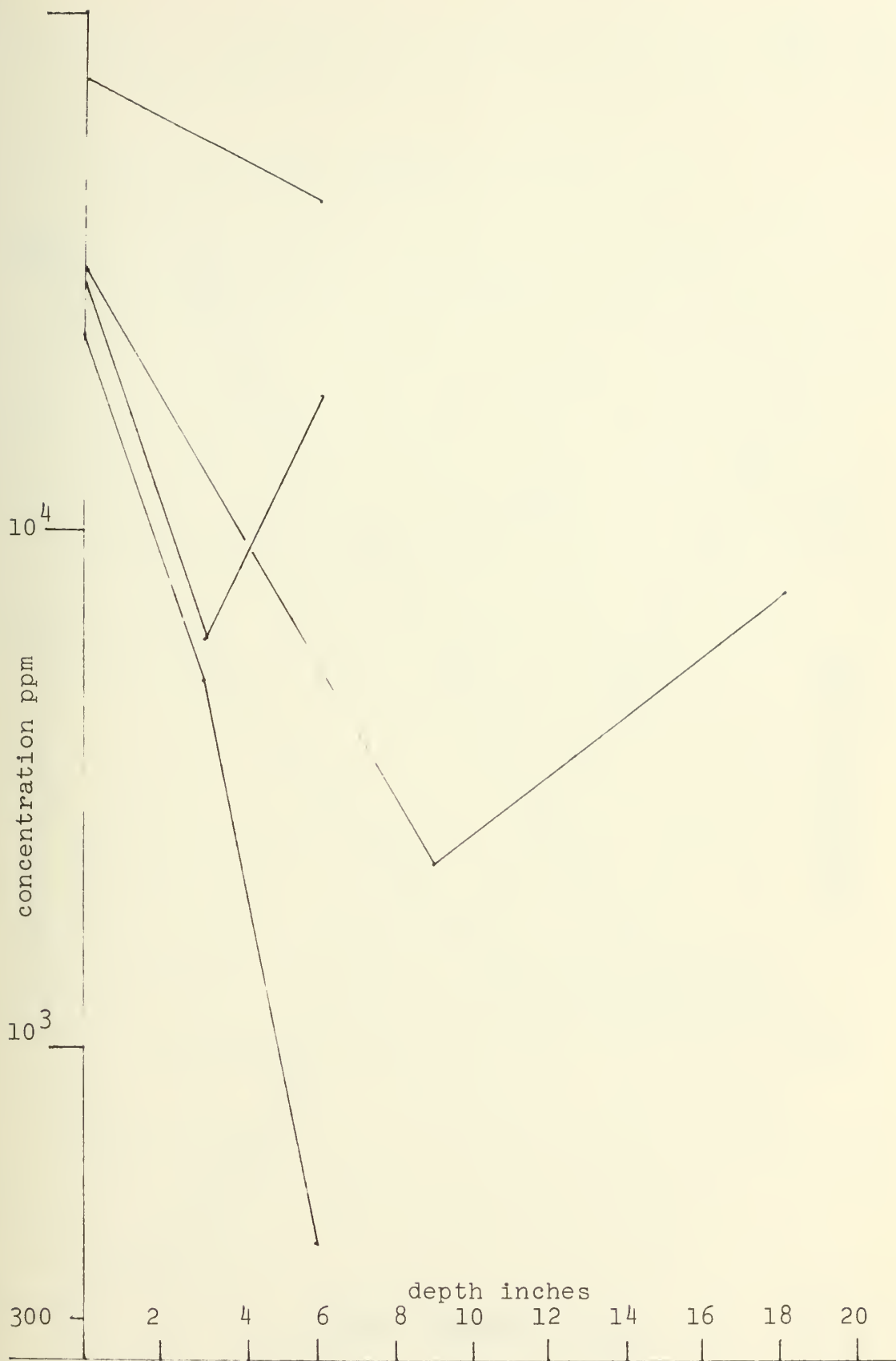
Figure 6-6.   Oil Concentration vs Depth in Navy
Distillate Engine Rooms.
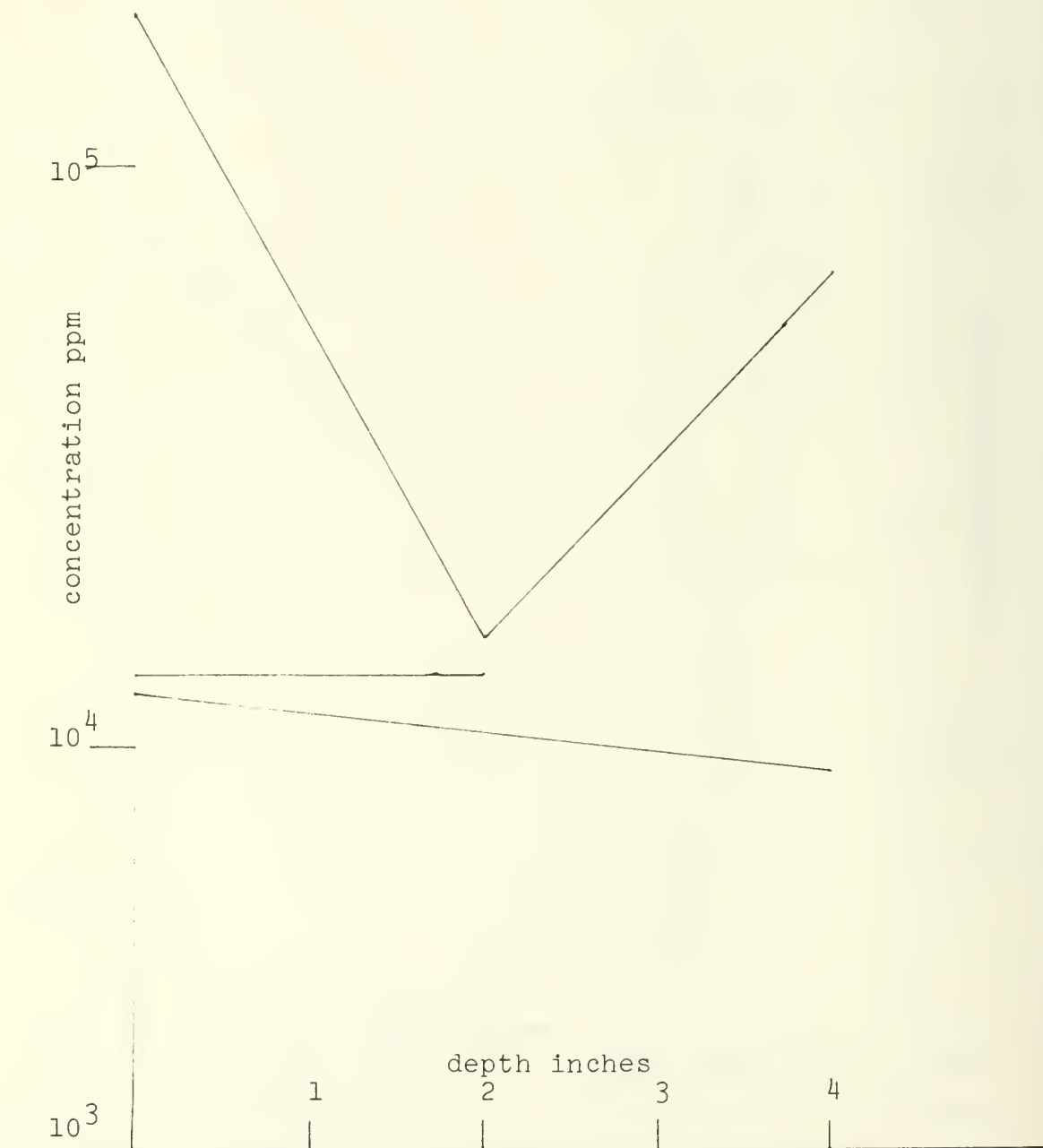
Figure 6-7.   Oil Concentration vs Depth
in Shaft Alley Bilges.
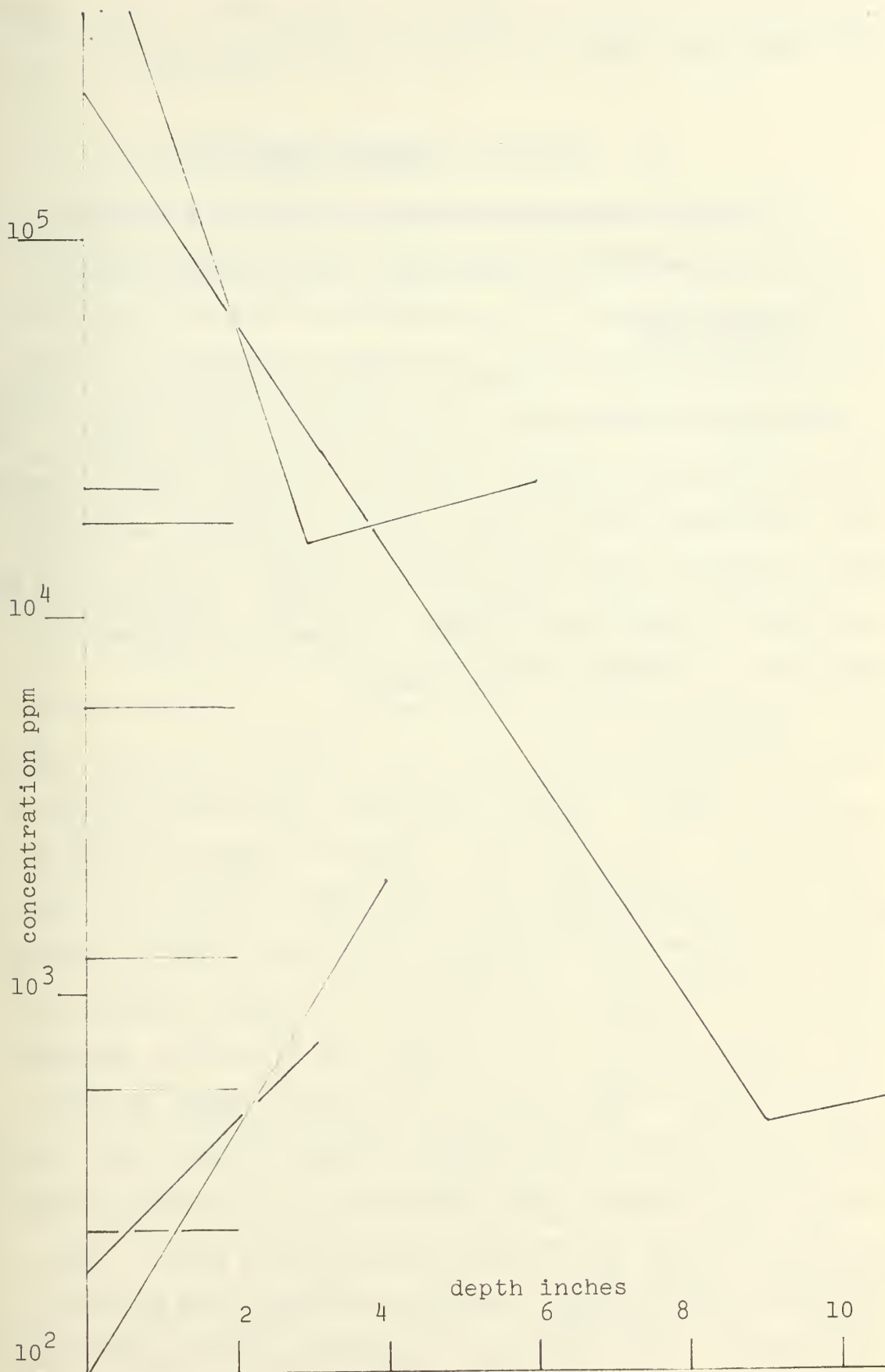
Figure 6-8. Oil Concentration vs Depth in Pump Room Bilges.

standards and thus the pumping of bilge water to the visible oil/water interface is not an acceptable procedure.

II.   BILGE OIL REMOVAL TECHNIQUES

Oil can be separated from water by various methods. Some of the most promising methods are described below.

A.   CENTRIFUGING

The centrifuge is ideally suited to separate two fluids of different densities in a rapid and efficient manner. Centrifuge systems, however, require an initial capital investment, periodic service maintenance and have the additional disadvantage of not being able to separate oil solutions and emulsions. Centrifuge systems are generally limited to separation above the 100 ppm range.

B.   COALESCENCE

The coalescer process separates fluids of different viscosities. Two dissimilar fluids are passed through a fine filter where drag forces slow down the more viscous fluid particles allowing them to coalesce. Gravity separation of the coalesced particles can then take place due to density differences. This process can be used to separate a more viscous fluid such as oil in an oil-water mixture. The main advantage of coalescer systems is their high separation potential. The coalescer is in a sense a water polisher and can separate to the solubility limit. The coalescer system require capital investment and periodic maintenance. Coalescers can not separate oil solutions and

emulsions. Colloidal filth tends to clog the filter and reduce flow rates.

C. BIOLOGICAL DEGRADATION

Nearly all types of hydrocarbons are susceptible to microbial degradation. More than 62 different strains of microbes have been identified as "oil eaters" of which only three are naturally occurring in the world's oceans. Microbial degradation converts oil to CO_2, water and biomass. Degradation can be enhanced in several ways. Microbes best suited for a specific type of oil can be concentrated and the oil can be chemically enriched by the addition of oxygen and nutrients. Microbial degradation directly addresses the oil disposal problem. All other methods of separation merely transfer the problem from one area to another. Microbial degradation removes the pollution problem of pumping bilges by converting the oil to biomass. After the degradation of the oil is complete, the bilges can be pumped in the normal manner. Microbial degradation requires no capital investment for processing equipment. The only cost is for the starter packages of concentrated microbes. One serious drawback to biological degradation, however, is the possibility of contamination of the fuel tanks. It is possible that the microbes could be inadvertently introduced into the fuel tanks, eventually converting the fuel to water and biomass. Once having contaminated a fuel tank, the microbes could cause a residual problem by remaining in the cracks and pits in the metal of the fuel tanks.

D. MAGNETIC LIQUIDS

If a ferro-fluid miscible with one phase of a two-phase mixture such as oil and water is added to the mixture, the mixture is rendered magnetically responsive. When the mixture is passed through a magnetic field the diamagnetic phase separates from the magnetic phase. From chemically stabilized emulsions, this process has produced waters containing less than 10 ppm oil.

E. MEMBRANES

Oil can be separated from water by cellulose acetate membranes leaving a filtrate with concentration below 25 ppm. Membranes are very fragile, however, and are rapidly coated with oil which reduces efficiency.

F. LIQUID-LIQUID COUNTERCURRENT EXTRACTION

A countercurrent liquid-liquid extraction system relies on the ability of a liquid such as carbon tetrachloride to capture oily material. The carbon tetrachloride, being very dense, should readily separate from the oily waste water and can then be recycled.

G. FREE VORTEX

A free vortex can be successfully used to separate a mixture of oil and water where the oil is present as a layer at the surface of the mixture. An impeller assembly is located beneath the surface of the water. When it is rotated rapidly, a vortex is formed. Oil floating on the surface is drawn into the center of the vortex creating a

pocket of oil that can be pumped off. The free vortex con-
cept may be adapted to a floating skimmer to remove oil from
a bilge.

H. GRAVITY SEPARATION

Gravity separation is ideally suited to separate fluids
of different densities and low solubility. In this process,
the two fluids separate because one fluid, being less dense,
will float on the other, thereby allowing easy collection of
each fluid. Fine dispersions of phases can be separated by
passing the mixture through baffles and allowing the par-
ticles of the less dense fluid to coalesce. The coalesced
drops then rise and can be collected. Gravity separators
can not separate oil solutions and emulsions, but are usually
less expensive to purchase and maintain than other mechanical
separators.

I. SUMMARY

Separation techniques such as evaporation, distillation,
electroseparation and freezing are not discussed because
of the need for either heavy equipment and/or large supplies
of power.

Separation techniques such as centrifuging and coales-
cing have major drawbacks as complete solutions to the bilge
oil pollution problem. Initial studies indicate that the
solubility of Navy Distillate in water is as high as 500 ppm.
Both systems will thus produce effluents with oil concen-
trations in excess of Navy standards.

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A mechanical separation system would require a combina-
tion of separation techniques in order to meet the minimum
Navy oil effluent standards. The initial stage would be a
gravity or vortex separator to remove the bulk of the oil,
followed by a coalescer to reduce the oil concentration to
the solubility limit. The final stage would be a membrane
filter to remove any remaining oil.

III. BILGE OIL REMOVAL SYSTEMS

A detailed survey of currently available oil water separa-
ation systems was conducted by contacting U.S. manufacturers
presently engaged in the manufacture of oil water separators
and/or related hardware and accessories. The major source
used in identifying the various manufacturers was Thomas
Register, 51st Edition, 1969. A total of 75 contacts were
established by letter and/or telephone.

Manufacturer's responses were examined with respect to
the following minimum performance criteria established by
NAVFAC.

1. A reliable rugged oil/water separator system adapt-
   able to shipboard environment for contaminated oil
   with flow rate 0-100 gpm with water effluent con-
   taining less than 100 ppm required, less than 15 ppm
   desired.

2. A reliable rugged oil/water separator as above but
   with 0-200 gpm flow rate.

Manufacturer's responses that were usable are tabulated in Table 6-1.

IV. TEMPORARY SOLUTIONS FOR CONTROLLING OIL POLLUTION FROM BILGE DISCHARGE

A. CRITERIA

Temporary solutions for controlling oil pollution from bilge discharge were examined with respect to the following criteria.

1. The system must meet the existing Navy specifications for flow rates and separation limits.

2. The system must be adaptable as a temporary measure.

3. The system must be able to be rapidly implemented.

4. The system must have a low initial cost.

5. The system must be reliable and have low maintenance.

With respect to these criteria, only three concepts seemed applicable; biological degradation, bilge ballast transfer and a modified harbor donut. Mechanical separators were discarded because of:

1. High initial capital expense for equipment.

2. Long shipyard time for installation.

3. High cost of replumbing the bilges.

4. Increased on-board weight and space requirements.

5. Increased maintenance work load for ship's company.

TABLE 6-1

Applicable Manufacturer's Responses

COMPANY	CONTACT	OPERATION	GENERAL FEATURES	DESIGN CRITERIA	REMARKS
Bioteknika 5510 Vine Alexandria, Va.	Mr. Byron A. Moe, President	biologic degradation	A microbe mixture is tailored for specific waste oil problem. A starter mix is introduced to the waste oil. The microbes multiply logarithmically and eat the oil converting it to CO_2, water and biomass. After the oil has been consumed, the microbes die.	A microbe mix can be designed for any type of waste oil problem. The microbes can live in a ph range of 4.5 to 10. A test bed at a cold rolling mill yielded a cost ratio of 0.086 cents per gal of waste.	The waste oil pollution problem is not relocated but neutralized. The company wishes to provide a clean-up service instead of supplying the microbes. They insist on controlling the degradation process.
Inland Environmental 5454 N.Wolcoit Ave.,Chicago, Ill.		gravity separation	The "Hydro-Gard 210" AP type oil water separator separates the oil from the water on the basis of the difference in their specific gravities. The oil, being lighter, rises and floats to the surface where it is removed by a skimming process. The sludge settles to the bottom for removal and the water is drawn off.	The "Hydro-Gard 210" has a flow rate of 210 gal/min and removes all oil particles 0.006 inches in diameter and larger. It measures 30'x6' and weighs in excess of 20,000 lbs. No cost data is available.	The unit comes prepackaged and ready to install. Its bulk may preclude shipboard use.

Figure 6-1 (Continued)

COMPANY	CONTACT	OPERATION	GENERAL FEATURES	DESIGN CRITERIA	REMARKS
Buterworth Systems Inc. E. 22 St. Bayonne, N.J.		gravity separation and coalescence	The Butterworth separator is a verticle cylindrical tank divided into three stages: 1. De-aerating and primary separation by settling, 2. Secondary separation and sediment removal, 3. water polish by coalescence.	The Butterworth unit has a flow rate of 1320 gal/min. The dry weight of the unit is 14,000 lbs. Unit dimensions are 9' by 16'. Cost and separation limits are not available.	The unit's bulk may preclude shipboard use.
Absolute Oil Separator Co. 57-15 32 Ave. Woodside, N.Y.	Joseph Schady	gravity separation	Oil/water mixture flows into a vessel where the oil rises to the surface and is drawn off.	The device has a flow rate of 125 gal/min. It weighs 900 lbs and has dimensions of 31" by 35" by 59".	When oil trap is full, flow is shut off.
Pennwalt Corp. 955 Mearns Rd. Warminster, Pa.	Albert Zambone	centrifugation		The "Sharples" centrifuge has a flow rate of 500 gal/min. The unit meets Merchant Marine stds.	
De Laval Separator Co. 1815 Rollins Rd. Burlingame, Calif.	J.A.Doot	centrifugation		The De Laval Co. will manufacture to specifications.	

Figure 6-1 (Continued)

COMPANY	CONTACT	OPERATION	GENERAL FEATURES	DESIGN CRITERIA	REMARKS
Mapco Inc. 1437 S. Boulder Ave. Tulsa, Okla.	E.L.Korner Techrad 6323 N. Grand Blvd. Okla. City, Okla.	coalescence	The Banner oil/water separator separates the oil from the water by forcing the mixture through a filter that retains the oil until large drops are formed. The coalesced oil drops rise to the top of the filter element and into the oil collection dome where the oil is drawn off.	The Banner oil separator is manufactured with flow rates up to 2,000 gal/min and a separation potential down to 10 ppm. A 1,000 gal/min unit, less the pump and installation, costs $5,000. Unit size and weight not available.	The Banner separator cannot handle an emulsion.
Fram Box 500 96 Tulsa, Okla.	O.C.Redmon	gravity separation	The separation of oil from water is achieved in two stages. First the oil/water mixture enters the vessel into the first stage quiescent zone where the bulk of the oil will rise into the oil collecting chamber. The flow enters the second stage where the water and remaining oil flow at low velocities between plates. The remaining oil rises and is collected.	The Fram separator will handle 900 gal/min. The unit's dry weight is 5,000 lbs. Depth and height dimensions are 78" and 142". Cost and separation limits are not available.	The Fram separator has no moving parts.

TABLE 6-1 (Continued)

COMPANY	CONTACT	OPERATION	GENERAL FEATURES	DESIGN CRITERIA	REMARKS
International Pollution Control Systems Inc. 1729 H St. N.W. Suite 300 Washington, D.C.		gravity separation and coalescence	Oil is pumped from the bilge by a deep suction floating head into an air-liquid separator. The mixture is then run into a gravity separator. Oil and water are drawn from the bottom and into a settling tank. The last stage takes water from the bottom of the settling tank and runs it through a final filter.	The system has the capacity of 4.5 gpm and can separate down to 3 ppm. The system's dimensions are 4.5' by 3' by 5' and weighs 700 lbs.	This system is installed on the Japanese Coast Guard Cutter "IZU".
Hamilton Standard Co. Windsor Locks, Conn.		vortex separation	The Hamilton separator employs a high strength vortex to generate separation forces.	The Hamilton separators have flow rates up to 1,000 gpm.	
Gerald C. Bower Inc. Orange, Calif.		biological degradation	DBC Plus Dried Bacteria Cultures Type L are introduced into the oil water mixture. The bacteria multiply logarithmically and "eat" the oil.		DBC bacteria cleaned the bilges of the Queen Mary in three days.
Separator and Recovery Systems Inc. 1733 Kaiser Ave. Santa Ana, Calif.	R.W. Chambers	coalescence	Coalescers are stacked in tandum.	Volume capabilities from 20 gpm to 600 gpm.	The company wants to lease the separators. $20/day=50gpm $30/day=100gpm $60/day=600gpm

B. BILGE BALLAST TRANSFER

Most ships in the Navy have tanks allocated for holding contaminated fuel oil. In many cases these tanks are used to increase fuel aboard in excess of Naval regulations. It has been suggested [Kaplan, L., 1971] that a simple solution to the waste oil pollution problem would be to pump bilge water into these tanks. In many cases the plumbing already exists to accomplish this. While underway, a Navy ship must refuel at least every four days to maintain fuel onboard requirements. The tankers after discharging their oil return to port empty. It would seem a simple matter to pump bilge waste to the tanker while taking on fuel. The tanker can store the bilge water until it reaches port where the bilge water can be transferred to a shore processing plant, or it can separate the bilge water using large-capacity separator units located on its decks. This concept is also applicable for ship-to-carrier refueling operations.

This concept hinges on the fact that a Navy ship must use up its fuel faster than it fills up its bilges. One advantage of this system is that separation systems would not be required on individual ships, thereby saving space, money and maintenance work load on ship's company. This concept would also work while the ship is in port if the bilge water is pumped overboard into a barge or a yard oiler (YO).

C. DONUTS

The concept of using the common harbor donut to accept bilge water is presently being used. The donut is placed alongside a ship and bilge water is pumped into the donut's capacity of 72,000 lbs. When full, the donut is towed away and an empty donut is left in its place. The donut presently in use in San Diego has been modified with a bottom and a gravity pumping system (Figure 6-9). Two such donuts are presently being constructed at the North Island Public Works Center. The production cost for these two donuts is presented in Table 6-2. The main advantage of this concept is that it requires no shipboard modifications. There are several disadvantages:

1. The concept is not applicable while the ship is underway.

2. High initial expense for the equipment.

3. The donuts are bulky and hard to tow.

4. Existing donuts must be modified with a bottom to prevent oil leakage while being towed.

D. BIOLOGICAL DEGRADATION

Microbial degradation of oil in the bilges is an intriguing solution for eliminating oil pollution. Several important aspects of this concept must be investigated:

1. The effect of the biomass on the environment.

2. The possibility of fuel tank contamination.

3. The extent of the degradation completed before the bilges fill up.
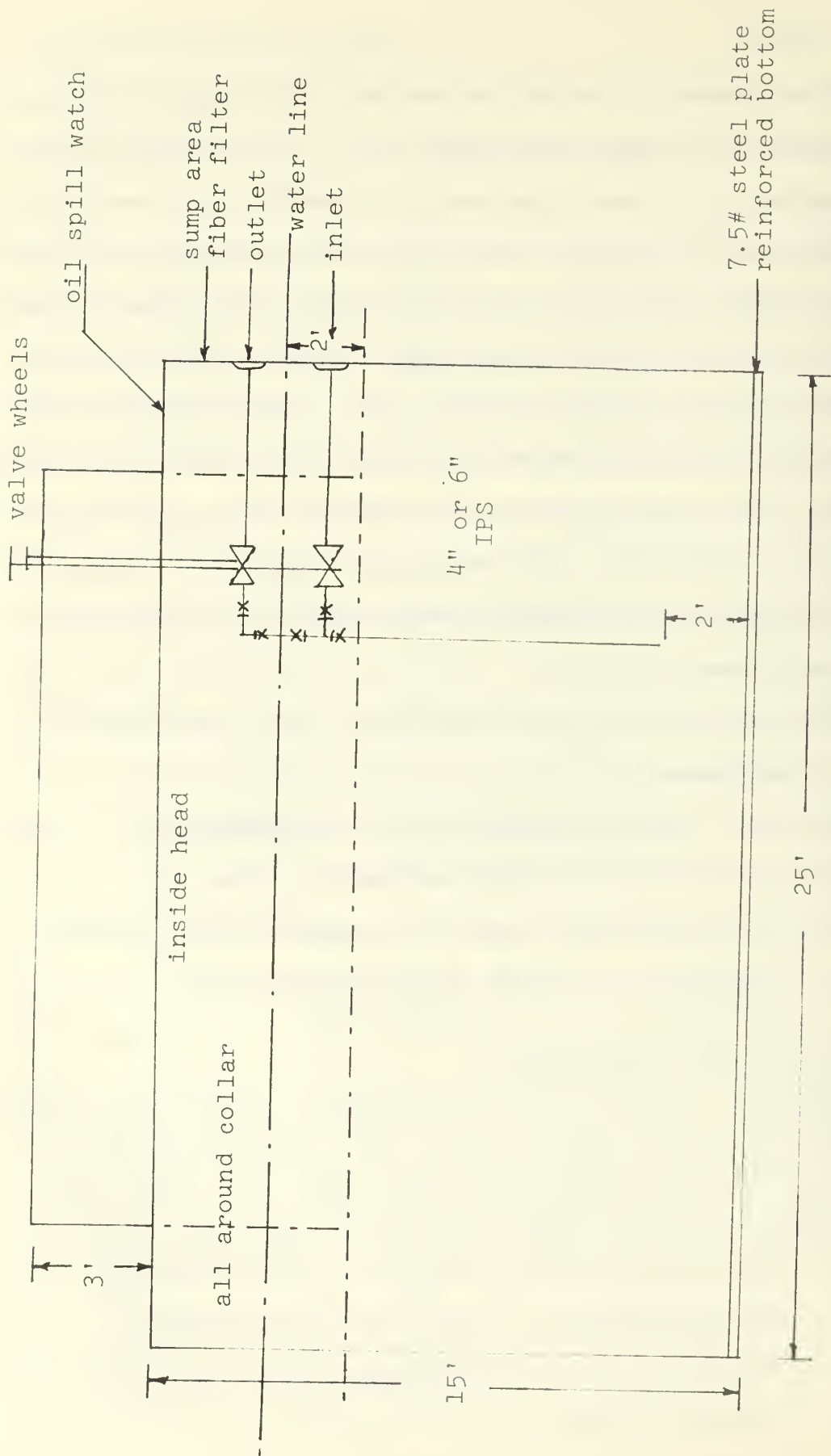
Figure 6-9. Buships Plan for 25' Oil Disposal Raft.

oil spill watch
valve wheels
sump area
fiber filter
outlet
water line
inlet
7.5# steel plate
reinforced bottom
4" or 6"
IPS
inside head
all around collar
2'
2'
3'
15'
25'

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TABLE 6-2

Cost for Two Oil Donuts

DESCRIPTION	LABOR HOURS	LABOR $	MATERIAL $	TOTAL ESTIMATE $
Prime and Paint All Metal Surfaces with Epoxy	52	494	640	1,134
Install Pipe and Valves	80	696	1,052	1,748
Sandblasting	100	850	123	973
Fabricate Two Donuts	2,106	20,546	8,124	28,670
Equipment Rental			1,193	1,433
Taxi	22	186		186
Heavy Trailer Transportation and driver	13	113		113
Hoisting & Portable Operator	42	378		378
Riggers	92	860		860
Equipment Rentals	100	1,000	1,020	2,120
TOTAL	2,607	25,223	12,392	37,615

4. The optimum method of introducing the microbes to
the bilges and of controlling their population.

V. CONCLUSIONS

Analysis of bilge water has shown that oil at all levels
in the bilges of Navy ships is in concentrations above Navy
effluent standards; therefore, the pumping of untreated
bilge water from any level is not an acceptable procedure.
It is thus necessary to treat the bilge water in some
manner to reduce the oil concentration prior to discharge.

Many methods for removing oil from water were examined, but only three methods were applicable as temporary solutions for controlling pollution from bilge water discharge; biological degradation, bilge ballast transfer and the harbor donut. Mechanical separation systems such as centrifuges and coalescers were discarded as solutions for controlling bilge discharge pollution because of their cost, installation time, and failure to meet effluent specifications.

Of the three proposed temporary solutions, biological degradation appears to be the most attractive because of low cost, rapid implementation and total oil removal potential. It is therefore recommended that a test bed be procured for a biological degradation system.

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CHAPTER SEVEN

OIL SPILL CHARACTERISTICS AND STATISTICS

LCDR James M. Lacey

Abstract: This chapter summarizes historical data on time,
location, origin, and the removal costs of oil spills that
have occurred in San Diego Bay over a 5¼-year period. It
was found that costs were highly correlated with the fre-
quency of oil spills. Regression equations were developed
for describing the various relationships among cost,
frequency, and time. These data were shown to be influenced
by short-term time effects.

I. OIL SPILL CHARACTERISTICS

The five main oil spill characteristics that this chap-
ter discusses are the time, location, size, origin, and the
removal cost. This information has been maintained in an
Oil Spills Log by the 11th Naval District since 1 July of
1966 and was extracted from oil spill messages and contractor
invoices. As several messages sometimes cover the same
spill, there has been some redundant data listed in this log.
These excess entries are very difficult to detect and may
lead to differences in tabulations.

Very little literature can be found on these five
characteristics except for the subject of cost. The diffi-
culty in defining and pinpointing their occurrence
undoubtedly accounts for this shortage. These traits are

influenced by many varied factors, which affect their use-fulness as input data.

This chapter summarizes the frequency and monthly costs of oil spills and classifies them as to their origin and their location. A method of regression analysis establishes various relationships among cost, frequency, and time. These relationships are studied to determine if they have been influenced by any sort of a time effect. Recommendations for future studies in this area are discussed.

A. TIME OF AN OIL SPILL

When an oil spill occurs in the Navy harbor at San Diego, the vessel responsible is required to report it immediately to the Waterfront Operations Department [NCEL-NAVFAC, 1971]. For many reasons, a vessel commander may not always realize immediately that his ship has generated a spill. This may be due to limited visibility caused by weather or darkness, occurrence in an inaccessible location, or even due to inef-ficient watch-standers. Often a considerable amount of time has elapsed before the slick is detected and reported. Early detection is usually made when a ship is refueling, transferring fuel, or pumping bilges as all concerned hands are aware of the dangers involved and are alerted for the detection of oil slicks.

Since accurate data for the actual time of an oil spill was, for the most part, unattainable and usually not listed in the Oil Spills Log, it was felt that one-month frequency intervals were adequate for statistical purposes.

B. LOCATION OF AN OIL SPILL

The location of an oil spill is usually described as the specific area where the oil slick was originally detected and reported. However, the actual spill may have occurred in another location. Several factors affect the movement of oil with local wind velocity and direction being the most significant. The local speed and direction of tidal currents, which may be related to local wind conditions or perhaps prevailing currents of a more permanent nature, are also extremely important [Dillingham, 1970]. Oil tends to drift in the direction of and at about 3.3% of the velocity of the surface wind [Teeson, 1970]. This is independent of the type of oil, the depth of the water, or the amount of contamination in the water. Surface currents transport the oil at about the same speed as the current itself [NCEL-NAVFAC, 1971].

San Diego Harbor has been divided into five general areas for this analysis. These are the Naval Station, North Island, buoys, fueling pier, and a residue collection called "others." This particular division was selected in order to be compatible with the Oil Spills Log.

C. SIZE OF AN OIL SPILL

Size is undoubtedly the most difficult characteristic to assess, since there is no reliable method for determining the amount of oil that has been spilled. In general, the estimates of the quantity of oil spilled tend to be very low. One slick 20 feet wide and 2 miles long was reported to be

caused by only 1 gallon of oil. It is extremely unreliable to assess the amount of oil spilled by the size of the occupied area. Tests made by the Shell Oil Company in the Gulf of Mexico have shown that whether 1 barrel or 5000 barrels are spilled, after 24 hours either amount will essentially spread over the same area [NCEL-NAVFAC, 1971]. Furthermore, evaporation is probably the most important process with volatile fuels such as JP-4 and JP-5. A spill of about 25000 gallons of volatile fuels, reportedly, will evaporate in about 2 or 3 hours. Thus, visual estimation of oil spill size is unreliable.

Since the size of an oil spill cannot be accurately determined with any degree of confidence, this analysis declined to use that data.

D. ORIGIN OF AN OIL SPILL

One of the big problems in determining the origin of a spill is hesitation on the part of a vessel commander to report that his ship has caused a spill. Often, the crew attempts to disperse the spill with fire hoses, sand, water, foam, or any other means at hand. This only spreads the spill [NCEL-NAVFAC, 1971]. With several ships tied to a pier, it is often difficult to determine which ship created the spill. Certainly no commanding officer will accept the guilt unless he is absolutely positive that his vessel was responsible.

The ships that were identified in the Oil Spills Log as the Origin of Spill (Ship) were categorized into various

types. These were destroyers, amphibious, cruisers, car-
riers, tenders and repair, oilers, others, and unknown for
the unidentified ships.

E. COST OF AN OIL SPILL

The overall cost involved in oil spill cleanup is fully
discussed in Chapter Ten. For this chapter, the cost of an
oil spill is the amount of money that the Navy pays to a
contractor for the physical containment and removal of oil.
Many underlying factors cause this figure to vary widely.
Among these are the size of the contaminated area, the type
of oil spilled, the local atmospheric conditions, the local
sea conditions, the locality of the area to be cleaned, and
the system of oil removal.

The larger the contaminated area, the more equipment,
personnel, and time that will be required for clean-up.
As mentioned previously certain types of volatile fuels will
start evaporating before clean-up crews can be deployed.
The local atmospheric conditions will influence control
activity but will have little effect on the behavior of
the oil itself. Poor visibility due to fog or rain may have
the most significant effect by restricting vessel operations
as well as limiting visual detection of drifting oil slicks.
Wave heights of above two feet cause most recovery devices
to become ineffective and even to experience structural
problems [Dillingham, 1971]. The Navy's primary problem,
identified in a study of some 42 Navy activities, is the
small, chronic spill--often less than 200 or 300 gallons--

in congested areas, where operations cannot be shut down and
ships moved to facilitate cleanup. The different systems of
oil removal are discussed in Chapter Eleven.

II. OIL SPILL STATISTICS FOR SAN DIEGO BAY

In this phase of the study various statistical techniques
are used to analyze and interpret the available data on oil
spills in San Diego Bay. The purpose here is to increase
the understanding of oil spill characteristics and identify
any existing trends. For a more thorough discussion of the
statistical techniques used, the reader is referred to a
basic text in applied statistics.

The contractor's invoice costs, as listed in the Oil
Spills Log, were totalled for each month as was the frequency
of oil spills. These were used as the basic input data.
They were further classified according to the type of ship
that spilled the oil and to the location of the oil spill.
These results are given in Tables B-1 to B-4 of Appendix B
and a summary is listed in Table 7-1.

It should be pointed out that the Naval Station presently
is cleaning up certain minor oil spills in its area, but a
sufficient amount of data has not been generated for this
activity. Therefore this information will not be reflected
in this analysis.

TABLE 7-1

Total Spills and Costs for Ship Type and Location

	TOTAL SPILLS	% OF SPILLS	TOTAL COST	% OF COST	AVERAGE COST OF SPILL
SHIP TYPE					
Destroyers	190	32.04	$ 61317.46	23.93	$ 322.72
Amphibious	74	12.48	31616.38	12.34	427.25
Cruisers	26	4.38	5985.43	2.34	221.68
Carriers	55	9.27	29297.10	11.44	532.67
Tenders & Repair	25	4.21	33150.32	12.94	1381.26
Oilers	16	2.70	6250.55	2.44	390.66
Others	41	6.92	6325.97	2.47	154.29
Unknown	166	28.00	82244.26	32.10	495.45
TOTAL	593	100.00	$256187.47	100.00	
LOCATION					
Naval Sta.	380	64.08	170842.20	66.69	449.58
North Is.	108	18.21	61247.94	23.90	567.11
Buoys	40	6.75	7602.50	2.97	190.06
Fueling Pier	12	2.02	7045.11	2.75	587.09
Others	53	8.94	9449.72	3.69	178.30
TOTAL	593	100.00	$256187.47	100.00	

A. COSTS AND FREQUENCIES

Table 7-1 shows that there have been 593 oil spills reported in this 63-month time period. The destroyer type of ship has been charged with 190 of these or 32% of the total. The spills listed as unknown origin accounted for 166 (28%). Next were the amphibious type of ship, which was charged with 74 (13%) spills. This table also shows that the Navy has been reportedly charged $256,187 for spill cleanup in the

same time period. The costs attributed to unknown origins totalled $82,244, which was 32% of the total cost. Destroyers accounted for $61,317 (24%). The next highest cost was listed for tenders and repair ships, which were charged with $33,150 (13%).

A recent study by Kennedy Engineers has stated that the estimated average number of destroyer type of ships was 37 out of an average total of 65 vessels in San Diego Bay [Kennedy Report, 1969]. Since destroyers comprised the largest percentage of ships, it is not surprising that they have caused more oil spills than any other type of ship. However, any oil spill prevention program should be focused upon the destroyer type of ship. If one can assume that the number of spills listed as unknown was distributed among the other ship types in proportion to their reported number of spills, then destroyers were responsible for about 41%. Using the same assumption for clean-up costs, this same type was accountable for about 31%.

A similar type of analysis can be applied to the locations of oil spills. Table 7-1 shows that the Naval Station has had 380 spills, which was 64% of the total. North Island has reported 108 (18%) spills. In the study of costs, the Naval Station has accounted for $170,842, which was 67% of the total cost. In the same time period North Island had $61,248 (24%).

The study by the Kennedy Engineers stated that the average number of ships berthed at the Naval Station was 62,

whereas at North Island there were usually only 3. Once more the argument can be presented that since there were more ships berthed at the Naval Station there were bound to be more spills there, and the data shows that over a 5¼-year period the Naval Station has had the greatest number of oil spills and also the highest clean-up costs. Therefore, if the Navy decides to contain and remove all of their own spills, the Naval Station would certainly warrant the largest concentration of resources for this task. This is discussed further in Chapter Eleven.

Table 7-1 also shows that the highest average cleanup cost, $1381, was incurred by the tenders and repair ships. The carriers were next with an average cost of $533. Thus, these two classes of ships do not have many spills, but the cost of cleaning up each spill is apparently very high.

In the study of locations of oil spills, the same type of statistic was revealing. The fueling pier had a very small number of spills, but the average cost for each spill was high ($587). Chapter Nine states that a ship is fully manned and in a complete state of fueling readiness prior to transferring fuel from the fuel pier. Because of these favorable conditions, the number of oil spills will be very small. However, due to the type of operation being conducted, the size of a spill will probably be very large. North Island had the next highest average cost of $567 and the Naval Station had an average cost of $450. Thus, there does not appear to be a significant difference in the average cleanup cost of a spill for these three areas.

B. REGRESSION OF COST ON FREQUENCY

Since the clean-up cost is related to the number of oil spills, a method of fitting an orthogonal polynomial to the data was used [Graybill, 1961]. The general statistical model is

$$Y = b_o + b_1 X + b_2 X^2 + \ldots + b_n X^n + \varepsilon$$

where Y, the dependent variable, is cost and X, the independent variable, is the frequency of oil spills. ε is an error term which is assumed normally distributed with a mean of zero and an unknown variance.

The accepted procedure is to first fit a linear polynomial, then a quadratic, then a cubic, and so forth, until the polynomial that fits the data "best" is determined. This method is fully explained and the results given in B-5 of Appendix B. It was concluded that a simple linear regression equation provided the "best" fit. This equation is the same as one would obtain with a conventional regression analysis using the method of least squares. Here the parameters are estimated by minimizing the sum of the squares of the vertical distances from the regression curve [Ostle, 1966].

Figure 7-1 illustrates the values of the observed costs and the predicted values from the regression equation.

The average or mean frequency of oil spills was 9.4 and the resulting average or mean cost was $4066 for a month. The correlation coefficient, which is a measure of correlation between the variables, was 0.73. This is an indication

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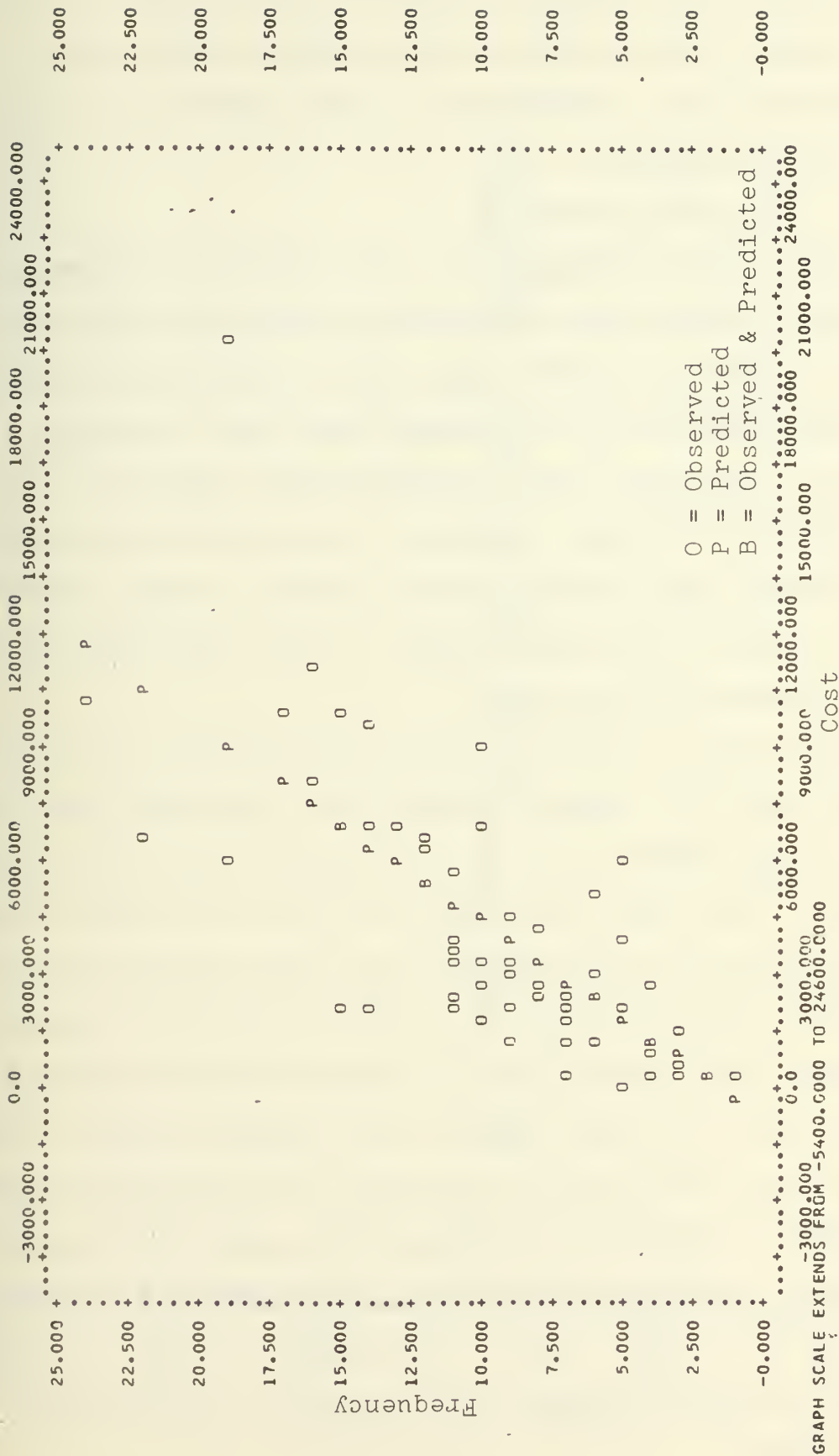
Figure 7-1. Plot of Observed and Predicted Values.

O = Observed
P = Predicted
B = Observed & Predicted

Cost

Frequency

GRAPH SCALE EXTENDS FROM -5400.0000 TO 24600.0000

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of how well the regression equation fits the data and will be close to 1 if the data points are very close to the regression curve. Therefore, the data appeared to be well fit by the equation

$$\hat{Y} = -785.3 + 515.4X \tag{1}$$

The plot of residual, i.e., the difference between the observed and the predicted cost in consecutive order of time, is shown in Figure 7-2. Notice that the points seem to form something of a horizontal band over the entire period. This shows that a long-term time effect was not influencing the data. However, a closer examination seems to indicate that the data tends to form a certain downward trend pattern that repeats itself. Thus, there appears to be a short-term time effect.

The method of determining this time effect was one of trial and error. Dummy variables were introduced that consecutively numbered each month within the length of the time period. These were then varied until the multiple correlation reached its maximum value while the standard error of estimate reached its minimum. Thus, the intention was to decrease the standard error of estimate while increasing the correlation. The best results were obtained using a 12-month time effect with July of 1966 being the first month included.

With the addition of a time effect, the data for cost and frequency was best represented by the regression equation

$$\hat{Y} = 412.7 + 500.5X_1 - 168.3X_2 \tag{2}$$

where X_1 denotes frequency and X_2 denotes the associated time effect.

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Figure 7-2. Time Sequence Plot of Residual Costs.

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A high monthly clean-up cost has been followed by down-ward sloping costs for the next 11 months. Then the cost starts to sharply increase and the pattern repeats itself.

One possible reason for this is that during the summer months, when all Naval activities tend to have a large turn-over of personnel, the experience level of the ship's crew is usually lower than at any other time of the year. Then as the experience level increases, the number and the cost of spills tends to decrease until the following summer, when personnel rotations are large again. Thus, the cycle starts to repeat.

Another possibility is that following a high monthly cost, there is probably a lot of pressure placed on the ships to prevent future spills. As time passes and the number of oil spills keeps decreasing, the emphasis on prevention also decreases. The downward trend keeps continuing until there is a high monthly cost, which brings about the same pattern.

C. REGRESSION OF COST ON TIME

In order to examine the dependence of cost on time, a linear regression was run, which resulted in

$$\hat{Y} = 2732 + 41.7X$$

where $\hat{Y}$ is the cost estimate and X is time.

The correlation coefficient here was very low, 0.22, which means that our linear regression equation does not fit the data very well. Along with this goes a high standard error of estimate, 3427.72.

A t-test was then used to determine whether the coefficient of X could be regarded as zero. The hypothesis was that $b_1 = 0$ and a computed t value was 1.76. The critical t value, extracted from the t-distribution table with 61 degrees of freedom and at the 95% level, was 2.00. Since the computed t value was less than the critical value, the hypothesis $b_1 = 0$ was accepted.

The length of the time effect for the cost data was determined to be 16 months. The multiple correlation reached its highest point of 0.33 while the standard error of estimate was at a minimum of 3258.87. Thus the data was better fit, when the time effect was introduced, by the regression equation

$$\hat{Y} = 4416.8 + 55.3X_1 - 252.9X_2 \qquad (3)$$

where X_1 was the time variable and X_2 was the associated time effect.

Again a t-test was conducted to determine if the coefficients of the X's were zero. The computed t value, in both cases, was greater than the critical t value from the table at the 95% level and both hypothesis ($b_1 = 0$ and $b_2 = 0$) were rejected with a risk of being wrong of less than 5%.

D. REGRESSION OF FREQUENCY ON TIME

To examine the dependence of spill frequency on time, a linear regression was run, which resulted in

$$\hat{Y} = 7.1 + 0.1X$$

where $\hat{Y}$ is the estimate of spill frequency and X is time.

The correlation coefficient was very low, 0.27, coupled with a relatively high standard error of estimate of 4.79.

The regression coefficient was found to be statistically significant at the 95% level.

As with "cost on time," there appeared to be no long-term time effect but a short-term effect of 16 months was noted. The multiple correlation reached a high of 0.37, a very noticeable increase, and the standard error of estimate a low of 4.66. The regression equation is

$$\hat{Y} = 8.9 + 0.1X_1 - 0.3X_2 \tag{5}$$

where X_1 was the time variable and X_2 was the associated time effect.

A t-test was run to determine if the coefficients of the X's were zero. Again the two hypothesis ($b_1 = 0$ and $b_2 = 0$) were rejected at the 95% level.

E. REGRESSION OF COST ON FREQUENCY AND TIME

The final analysis was conducted on the two independent variables, frequency, represented by X_1, and time, represented by X_2. Here the regression equation is

$$\hat{Y} = -888.3 + 510.8X_1 + 4.6X_2 \tag{6}$$

with a multiple correlation coefficient of 0.73 and a standard error of estimate of 2422.42.

A t-test was conducted to test the hypothesis $b_1 = 0$. This was rejected but the second hypothesis $b_2 = 0$ was accepted. Therefore, as expected, cost appeared to be dependent only on frequency and not on time.

F.   EXTENDED APPLICATION OF EQUATIONS

Although our data was associated with San Diego, the
approach used in this study could be taken for any location
where data is available. The statistical work should not
only describe the sample but should provide information
about the sampled population. Costs will vary according to
the size of the contaminated area, the type of oil spilled,
the local atmospheric conditions, the local sea conditions,
the locality of the area to be cleaned, the system of oil
removal, and the variation in standards. Since Equation (1)
has been derived from data peculiar only to San Diego, it
should not be applied as a prediction equation for other
areas. This is particularly true when it is known that the
other areas have different cost factors. For example; with
15 months of data from Long Beach, a regression of cost on
frequency yielded a low correlation coefficient of 0.27.
The mean frequency was found to be 5.5 and the mean cost for
a month was $4389. In comparison, the coefficient for San
Diego was 0.73 with a frequency of 9.4 and a monthly cost
of $4066. Thus, the number of spills for Long Beach was
almost half that for San Diego but the costs were about
equal. However, Equation (1) yielded a cost estimate of
$2049 for a given frequency of 5.5 spills.

III. CONCLUSIONS

Within the time period of 1 July 1966 to 30 September 1971, there have been 593 oil spills reported in San Diego Bay with an associated cost of $256,187. The destroyer type ships have been responsible for about 32% of these spills and 24% of the costs. It was determined that 64% of these spills occurred in the area of the Naval Station along with 67% of the total costs. Tenders and repair ships incurred the highest average cost of $1381 for each spill and the fueling pier averaged $587.

A linear regression equation was shown to offer a good fit for these data. When regressing cost on frequency, a slight time effect was found to exist with a period of 12 months. This time effect reduced the variation between the observed and predicted costs. A high correlation coefficient implied that the data was well fit by our regression equation. A similar regression for cost on time and frequency on time indicated that a 16-month time effect was influencing these data. In both cases, a low correlation coefficient was found, which suggests that the regression equations do not fit the data very well.

Using 15 months of data from Long Beach, a linear regression equation was found to offer a poor fit. Although San Diego averaged nearly twice as many spills, the average cost was nearly the same.

Future research studies may be able to confirm or revise
the conclusions set forth here in the light of newly dis-
covered facts.

IV. RECOMMENDATIONS FOR FUTURE STUDIES

This chapter has by no means exhausted the total research
possibilities for future studies. Lack of time and suffi-
cient data precluded further attempts for testing several
of these variables.

It is recommended that the local wind velocity and
direction, the local speed and direction of currents, and
the exact area of a spill be reported in the oil spill
messages and, subsequently, in the Oil Spills Log. This
type of data could be used to trace the movement of oil
slicks in order to locate the shore areas that have the
greatest danger of being polluted. If deemed necessary,
permanent booming of these areas might be advantageous to
the Navy.

Another area of further work that could prove fruitful
would be to examine the effect of a ship's crew experience
level on the frequency of oil spills. After assigning a
numerical description to the experience level, a statistical
analysis could be performed. If it could be shown that the
frequency of an oil spill was dependent on the crew's exper-
ience level, then the Navy would benefit by organizing a

formal training program in oil spill prevention for all concerned shipboard personnel.

Although the cost of an oil spill depends on many factors, as discussed in Section E, little information is known about how cost varies with the size of a spill. Therefore, if reliable data were available, this relationship could be determined. But until there is an accurate method to assess a spill size, no further work can be done in this area with any confidence in the results.

If the exact time of an oil spill were known, this variable could be used to determine the period of the day when most spills seem to occur. This relationship would enable a commander to know when his ship was most likely to have a spill. Then he could take positive steps for the prevention of oil spills during these critical periods.

V. ACKNOWLEDGEMENT

The data used in this chapter was provided by CDR R.D. Fasig, USN, Pollution Control Officer of the 11th Naval District. His cooperation and assistance is gratefully acknowledged.

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CHAPTER EIGHT

REDUCTION OF OIL SPILLS DURING SHIPBOARD
FUEL MOVEMENT EVOLUTIONS

LCDR James B. Greene, Jr.

Abstract: A large portion of the Navy's effort in approach-
ing the oil spill problem has been directed toward oil spill
cleanup. Relatively little progress has been made in the
area of oil spill prevention during fuel movement. A three
segment, SHIPBOARD CENTRAL FUELING STATION concept is pro-
posed and a cost analysis made of the materials and labor
required to implement this concept.

I.   PROBLEM DEFINITION

In reviewing the literature concerning oil pollution, it

becomes clear that the major thrust of the Navy's effort

has been directed toward the development of procedures and

machinery to accomplish the cleanup of "the inevitable oil

spill." A more positive approach to the problem, recommended

here, is to attempt to reduce the number of spills, thus

obviating the cleanup problem.

On October 30, 1970, the California Department of Fish

and Game published a report concerning the causes of oil

spills in the Los Angeles-Long Beach harbor during the period

1962-1969 [Putnam, 1970]. Of the 390 Navy oil spills inves-

tigated, 228 were related to fuel oil. In order to initiate

corrective action, it is important to investigate the causes

of these oil spills in detail.

The most frequently cited cause of fuel oil spills was that of overfilling a fuel oil tank. However, in each instance there were one or more personnel errors and/or equipment malfunctions that produced this visible end result. These existing preconditions, or lack of them, are the root causes of the oil spills.

Table 8-1 provides a listing of all of the causes, excluding overfilled tanks, cited for the 228 spills from Navy ships covered by the report and for the 95 spills from destroyer types involved in the fueling mishaps investigated. The destroyer information has been extracted because, in the analysis that is to follow, the choice of a particular type ship will enable the oil spill problem to be addressed more directly. Table 8-1 also shows that the causes have been divided into three major subgroups. These subgroups are CONTROL, INDICATION, and OTHER. The CONTROL subgroup contains those causes which could have been eliminated if a positive means of control of the fueling evolution had been in existence. The INDICATION subgroup is comprised of causes brought about by an inadequate tank level indicating system. The OTHER subgroup contains causes not covered by the first two subgroups.

Table 8-2 gives the fraction of causes attributable to each of these subgroups.

While there might be some debate as to the identification of the various causes listed in Table 8-1 as being either a CONTROL or INDICATION function, it is apparent that if both

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TABLE 8-1

Causes of Oil Spills

	NUMBER OF ALL NAVY SHIPS	NUMBER OF DD TYPES
CONTROL CAUSES		
Incorrect valve alignment	77	32
Top-off rate excessive	23	10
Communication problem	5	6
Did not consider list or drag	8	4
Blowdown from YO	2	2
TOTAL	115	54
INDICATION CAUSES		
Soundings infrequent or none	83	36
Obstructed sounding tube	1	1
Poorly constructed sounding tube	1	1
TOTAL	85	38
OTHER CAUSES		
Using overflow tanks as storage	33	2
Poorly lashed fuel hoses	5	5
Fuel hose rupture	4	–
Hull leaks	4	2
Leaking manifold	2	–
Faulty valves	2	–
Static pressure excessive	2	–
Ballast without tank back suction	1	–
Obstructed fuel line	1	–
Displaced gasoline header	1	–
Gravitated from shore	1	–
Uncapped riser	1	–
TOTAL	57	9

TABLE 8-2

Percentage of Causes of Oil Spills

SUBGROUP	% ALL NAVY SHIPS	% DD TYPES
Control	44.8	53.5
Indication	33.1	37.6
Other	22.1	8.9
TOTAL	100.0	100.0

causes are eliminated, so will 77.9% of the causes of oil spills for all Navy ships and 91.1% for DD types. Further support for this conclusion is gained by an analysis of the data contained in the Oil Spill Log and the message reports of oil spills held in files at the Eleventh Naval District Headquarters.[1]

This data indicates that clear-cut responsibility could be assigned for 57 oil spills during the period 1 December 1970 through 1 December 1971. Of the 57 spills, 24 were attributable to DD types engaged in fueling or fuel transfer evolutions. Classification of the causes of these spills indicates that 62.5% were attributable to either a CONTROL or INDICATION function. Consequently, a proposed method for improving the CONTROL and INDICATION aspects of the fueling evolution aboard DD types will be discussed in

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[1]This is the same data source referred to in Chapter VII, but here the time period used for the data analysis is different.

detail. It is expected that implementation of this system
will eliminate more than 90% of all destroyer oil spills.

II. PROPOSED METHODS OF OIL SPILL REDUCTION

Two methods of approach to the oil spill problem are
considered here. One approach, the INDIRECT approach, would
attempt to eliminate the causes that lead to overfilled
tanks. The existing overflow piping systems of ships would
not be altered, rather a system would be implemented to
provide instrumentation of all fuel oil tanks which overflow
overboard. This includes all storage, service, and contam-
inated oil tanks on most destroyers. However, some destroyers
presently employ an overflow tank concept whereby storage
tanks overflow into designated overflow tanks which in turn
overflow overboard. In ships employing this concept, the
only tanks necessary to instrument are the overflow tanks,
contaminated oil tanks, and service tanks. This assumption
will be made in the remainder of this analysis. The service
tanks are included because, while many do not have overflow
pipes as such, they vent to the main deck and present a
potential source of an oil spill. In addition, these tanks
are those most involved in everyday fuel transfer evolutions
and proper instrumentation of these tanks would considerably
ease the daily workload of the Oil King by eliminating the
many soundings now required to insure a proper fuel level
for servicing the power/propulsion plant. The emphasis

in the INDIRECT approach is on avoiding the rerouting of overflow piping, normally a costly process, while absorbing the cost of a large number of level indication installations.

An alternative approach, designated DIRECT, would be to minimize the possibility of overfilling tanks. This approach would involve reducing the number of tanks that overflow overboard by internally rerouting overflow lines to designated overflow tanks, which would have external overflow lines, and then instrumenting these tanks. A study has been made concerning the feasibility of rerouting overflow piping to accomplish this goal and the results were affirmative [NAVSECPHILADIV ltr 9480 Ser 1306, 22 November 1971]. The data presented in this letter will be utilized in the cost analysis of this approach. This procedure greatly reduces the number of level indication systems required, but incurs the cost of rerouting overflow piping. From an engineering standpoint, this would be the most desirable of the two · proposed procedures for two reasons. First, from statistical considerations, the fact that the number of overflow tanks is substantially reduced will by itself tend to reduce the number of oil spills. Secondly, the fewer number of gauges required by this approach will allow personnel monitoring the fuel transfer evolution to closely observe the level in the overflow tanks on a continuous basis.

III.   SHIPBOARD CENTRAL FUELING STATION

A.   SYSTEM DESCRIPTION

The basic concept to be proposed is the establishment of
a SHIPBOARD CENTRAL FUELING STATION (SCFS) aboard destroyer-
type ships.   This embodies the following:

    Subsystem I: installation of accurate, local tank
                      level indicators for all fuel tanks
                      (service, storage, and contaminated)
                      that overflow overboard.

    Subsystem II: installation of accurate, remote,
                      centrally located, tank level indi-
                      cators for all fuel tanks that
                      overflow overboard.

    Subsystem III: provision for an emergency shut-off
                      capability at the SCFS for both inter-
                      and intra-ship fuel transfer evolutions.

Each aspect of this proposal will be discussed and a cost

analysis developed.   It is to be emphasized that simultaneous

installation of these three subsystems is not only possible,

but considered essential if optimum results are to be

realized from this proposal.

B.   IMPLEMENTATION

    1.   Subsystem I

        The need for more accurate level indication on the

fuel oil tanks of ships of the destroyer force has long been

recognized.   This fact has been spotlighted recently in the

Navy Distillate Fuel Conversion program [NAVSHIPSYSCOM,

15 May 1971] and in recent correspondence at high echelons

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within the Navy [NAVSHIPSYSCOM ltr 9550 Ser 114-004, 13 July
1971]. In recognition of this need, a search was initiated
by the Navy to uncover a reliable tank level indicator
system. A device manufactured by the GEMS DIVISION-DE LAVAL
TURBINE appears to provide the reliability and accuracy
desired.

The reliability and another principle feature of this
system are described in the following quote:

> "The only available practical equipment which
> automatically compensates for specific gravity
> is the Type IC-MF equipment in accordance with
> MIL-L-23886. A review of this type of equipment
> currently in the Fleet indicated a high degree
> of reliability and a good degree of acceptance
> by Forces Afloat. Consequently, based on systems
> requirements as identified above, and with the
> confidence gained through the review of
> existing installations, NAVSHIPS/NAVSEC has
> recommended the use of Type IC/MF indicators
> in accordance with MIL-L-23886 for installation
> on all fuel tanks which have the potential for
> polluting the sea." [Jones, 1971]

Correspondence with GEMS DIVISION-DE LAVAL TURBINE indicates
that of 903 transmitter assemblies installed on submarines,
only 15 have experienced failures of any type over an average
period of 6 years constant service. Additionally, design
changes were initiated which eliminated the major causes of
a majority of these 15 failures. Replies to queries
addressed to ships of the destroyer force which have operated
with the GEMS installation support the reliability statistics
provided by the manufacturer,[2] although the operational

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[2] Approximately 20 destroyers have GEMS tank level indi-
cators installed in various numbers.

experience of these ships with these indicators is admit-
tedly somewhat limited due to the newness of the installa-
tion. Further, comments by operating personnel indicate a
wide degree of acceptance of this installation and, just as
importantly, a sense of relief that their ship finally has
an accurate means to monitor fuel oil tank levels, thereby
vastly improving their ability to monitor a fueling
evolution.

This tank level indicating system is of the magnetic
float, electrical type. Figure 8-1 is a schematic represen-
tation of the electrical circuitry involved in the system.
As can be seen, the voltage divider principle is employed
whereby a DC voltage is applied to a "resistor" and a por-
tion of this voltage is picked off by a "movable arm," the
float. Thus, the voltage indicated on the level meter will
increase as the float rises with the level in the tank and
vice versa. Figure 8-2 shows the actual, watertight, equip-
ment used in the tank, and the associated indicators. The
transmitter is a series of magnetic reed switches which are
activated as the magnetic float reaches them. This completes
the electrical circuit at the float level and "picks off"
the voltage corresponding to the fluid level in the tank. A
detailed explanation of all the components of this system
can be found in the technical manual developed for it [NAVY
DEPT, undated].

As can be seen from these diagrams, installation of this
device would appear to be a relatively easy endeavor, but
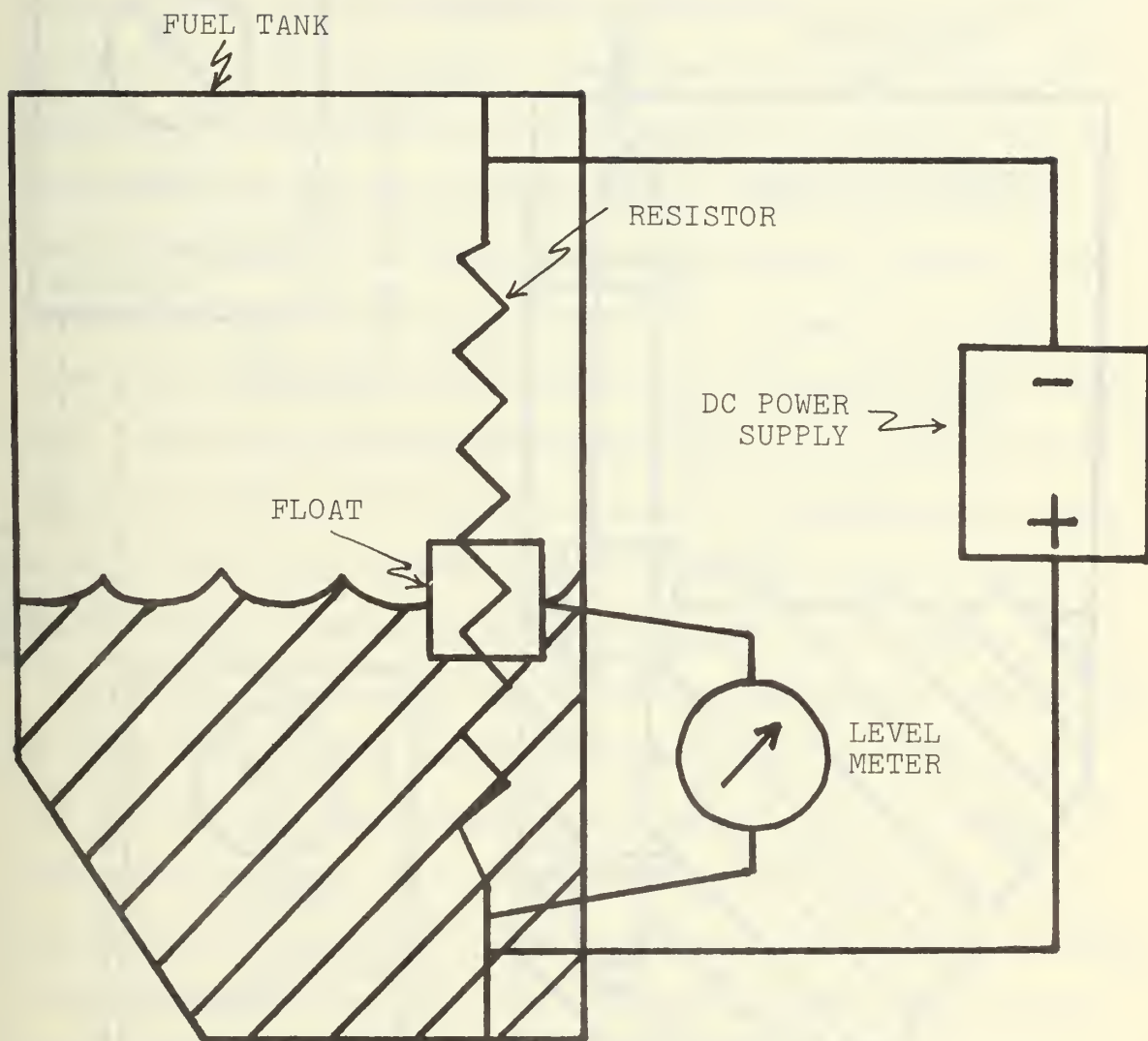
Figure 8-1. Tank Level Indicator Schematic Diagram.

KICK PIPE

FUEL TANK

CONNECTING CABLE

TRANSMITTER

FLOAT

LOCAL

RECEIVER/
INDICATOR

REMOTE

RECEIVER/
INDICATOR

TO 115v,
60 CYCLE
POWER
SUPPLY
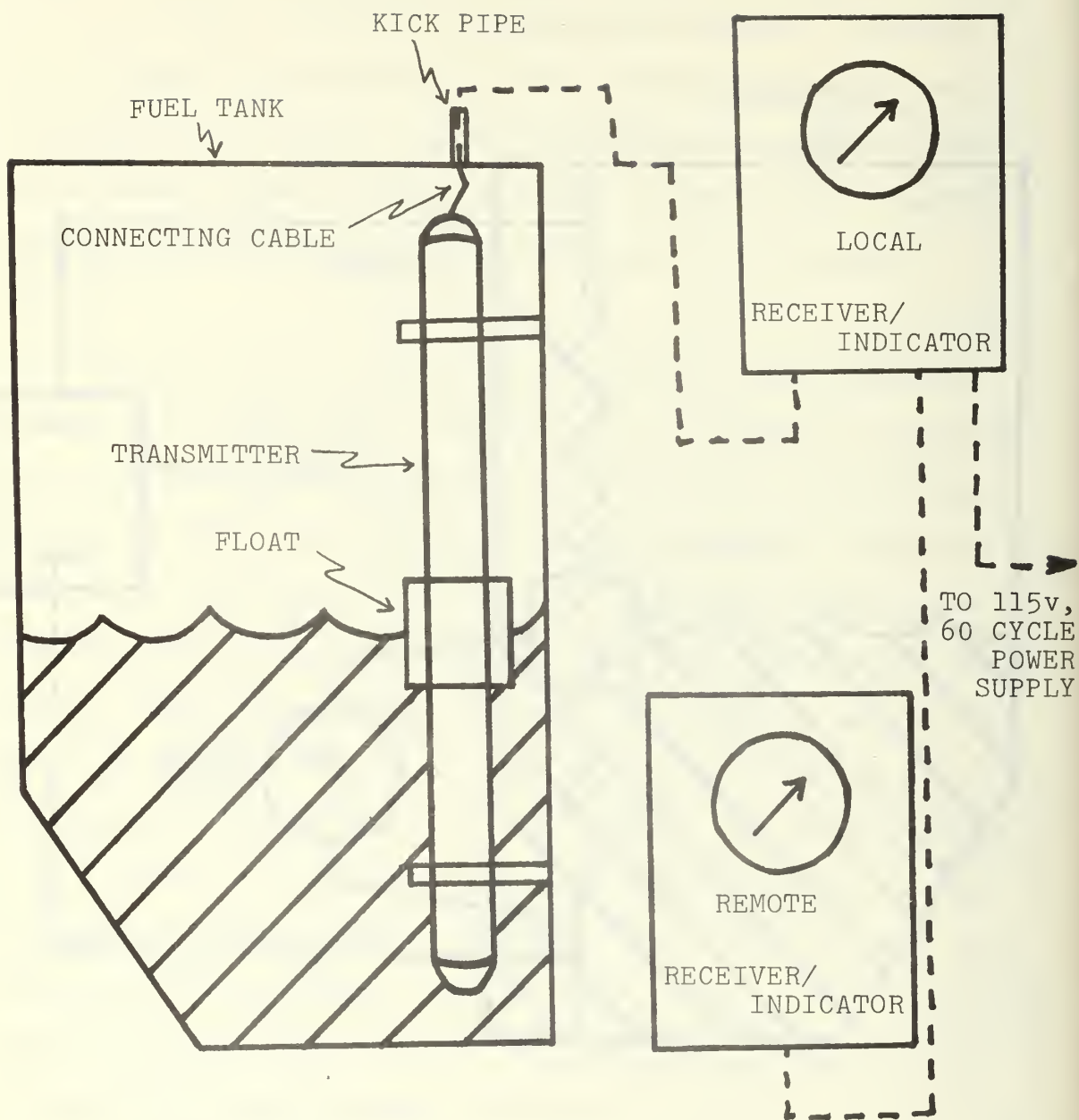
Figure 8-2.   Tank Level Indicator Hardware.

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one problem does arise in dealing with the cost aspects of the installation. The presently approved method for attaching the transmitting rod mounting brackets to the walls of the fuel oil tank is welding. In order to weld in a fuel oil tank, it is necessary to gas free the tank. This is usually accomplished by a process known as Wheelerizing which may cost in the neighborhood of $2,000 per tank [NAVSECPHILADIV ltr 9480 Ser 1834, 9 November 1971]. Consequently, much of the Navy effort to install this tank level indicator system has been tied to the Navy Distillate Fuel Conversion Program [NAVSHIPSYSCOM, 15 May 1971] during which the tanks of the ship undergoing the conversion are Wheelerized, thus providing a prime opportunity for the installation of this system. Unfortunately, initial supply problems have hampered this effort and a number of the ships which have undergone the distillate fuel conversion have not had the GEMS tank level indicators installed. Some ships have avoided the welding process by using frame bolt and sounding tube brackets to secure the transmitter assembly [NAVSECPHILADIV ltr 9480 Ser 1834, 9 November 1971]. If this method of installation is approved, a major constraint impeding the prompt installation of these tank level indicators would be removed.

Because of the substantial cost reduction to be realized by the elimination of the welding process in the fuel oil tanks, further research was done on this topic. Shipboard personnel were observed installing the GEMS tank level

indicator system without in tank welding.[3] The transmitting
assemblies were attached to either the access ladders in
the fuel oil tanks or the sounding tubes utilizing the
bracket and bolt approach. Interviews with the four-man
installing team indicated that they had every confidence
in this approach and that they were able to complete the
installation of the transmitting assemblies at the rate of
six tanks per day, each tank having 2 or 3 transmitting
assemblies installed.[4] In addition, only one hour per tank
was required to gather calibration data after the instal-
lation was completed. The ship's electrician's mates were
in the process of installing the necessary wiring, using
existing cableways, and were encountering no difficulties.

Additional emphasis was placed on the installation of
the GEMS system with the proposed issuance of Title D
SHIPALTS [NAVSHIPSYSCOM ltr 9550 Ser 114-004, 13 July 1971].
However, the classification of these SHIPALTS as Title D
is not expected to provide much in the way of support to
operating personnel of the Fleet in actually accomplishing
the GEMS system installation for the following reason.
Title D SHIPALTS are funded by the Type Commander out of
his own budget. There are many demands placed on these
funds by the Fleet and engineering problems are seldom given

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[3]Personal observation aboard USS RANGER (CVA-61).

[4]The depth of the fuel tanks on a carrier requires 2 or
3 transmitter assemblies if indication of the full liquid
level range in the tank is desired. On destroyer fuel tanks,
only 1 or 2 transmitters will be required.

high priority when in competition with the demands of the modern weapons systems and electronic gear installed on ships. Based on the foregoing discussion, it is strongly urged that the installation of the GEMS system be upgraded to the level of a program in itself and that funds be specifically earmarked for its accomplishment. The data of Table 8-2 indicates that 37.6% of the causes of destroyer oil spills will be eliminated by this step in itself.

2. Subsystem II

Subsystem II of the SHIPBOARD CENTRAL FUELING STATION concept deals with one aspect of CONTROL. No matter how accurate the tank level indicating system on a ship may be, it will be of little value unless it generates a response aimed at controlling the level in the tank. Present decentralized fueling arrangements on destroyers are nearly guaranteed to generate the type of human errors that result in oil spills. These errors are documented in Table 8-1 and are best handled by reducing the number of decision points during the fueling procedure. By constructing a centralized gauge board, with a gauge for each of the ship's fuel tanks having an overflow capability, the apparatus will be established to enable a central decision-maker to completely monitor any evolution involving the transfer of fuel. The GEMS system possesses the capability of providing remote indicators which can be fitted with either audio or visual alarms or both. It is proposed that each fuel oil service tank be fitted with a high and low level alarm at

the 85% and 30% levels, respectively, and that all storage
tanks possessing an overflow capability and all contaminated
oil tanks be fitted with a high level alarm at a level 10%
below the desired "full" limit of the tank.[5] Because of
the modular nature of these alarms and the fact that each
receiver is built with the receptacle for the alarm module
installed, installation of alarms can be accomplished at
any time merely by inserting the alarm module in the existing
receptacle.

It is expected that this central location will be the
Oil Shack which is already in existence on most destroyers.
From this vantage point, the ship's Oil King will be able to
monitor the fuel state of each tank on the ship.

Because of the large number of tanks that will require
level indication on ships not employing the overflow tank
concept, close attention must be paid to the arrangement of
the remote level indicators at the centralized monitoring
station. The wide variation in the dimensions of the spaces
utilized as the Oil Shack, and the structural interference
encountered therein, preclude the possibility of manufactur-
ing a standardized gauge board. However, the following
general guidelines are recommended:

    a. Indicators for the forward fuel system should be
        segregated from those for the after fueling system.
        A physical divider such as the proposed emergency
        shut off control is considered desirable.

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[5]See Chapter Nine for recommendations concerning this
limit.

b. Indicators for each fuel system (FORWARD/AFT) should
    be arranged in a left to right, top to bottom
    fashion, corresponding to the order in which the
    tanks in this system are normally filled during
    refueling operations. This implies that fuel oil
    service and contaminated oil tank indicators would
    be the last ranks in the gauging scheme.

c. Within the arrangement of b., indicators should be
    grouped by function (service, contaminated, fuel/
    ballast, overflow).

d. Maximum use should be made of mounting racks to
    accomplish the arrangement discussed above. This
    will tend to further emphasize the various indicator
    groupings and will conserve space. Mounting racks
    capable of holding six receivers are available from
    GEMS. The dimensions for a six-receiver, bulkhead-
    mounted, rack are 30" x 10" x 11 3/8".

An installation embodying these concepts is considered essen-
tial if a maximum reduction of possible error sources is to
be realized.

3. Subsystem III

    The final stage in the SCFS concept is providing the

Oil King with a positive means of control for all fueling

evolutions in the same location as his centralized gauge

board. It is proposed that this control be an EMERGENCY

STOP switch which will be wired into the local STOP control

of the fuel oil transfer pumps which are used for intra-ship

fuel transfer evolutions. In addition, a similar switch

would be wired to an external hull connection on both the

port and starboard sides of the ship. Upon refueling, this

connection would be attached by a portable cable length to a

hull connection on the yard oiler (YO) or fleet oiler (AO)

which would be wired into the STOP control of the fuel

transfer pump on the fueling ship. With this arrangement,

the Oil King would not only be able to monitor any fuel evolution on the ship, but could halt the flow of fuel if an emergency condition was indicated on his gauge board.

To further investigate the feasibility of this idea, Hunters Point Naval Shipyard was contracted to produce a drawing of this subsystem applicable to the USS JOHN PAUL JONES (DDG-32). The resultant drawing, NAVSHIPS DWG DDG-32-302-4474412, clearly indicates that this capability can be obtained by utilizing off-the-shelf materials. While the primary concern here is inport refuelings, this principle could easily be extended to refuelings at sea.

IV. COST ANALYSIS

Attention will now be directed toward the development of cost figures for the labor and parts required to fully implement the SCFS concept. Based on the demonstrated success of ship's force in accomplishing the non-welded version of the GEMS installation and the relative ease of installation of the emergency cutoff phase of the SCFS concept, it is recommended that all labor for GEMS installations be provided by ship's force. Using this approach, the only labor cost[6] in the process would be a GEMS "consulting fee" in payment for services rendered in familiarizing ship's force

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[6]In this analysis, no attempt has been made to attach a cost to the labor required by ship's force to accomplish this installation.

with the equipment and installation procedures. This cost
would be reduced if a Navy representative were trained to
perform this function. This is highly recommended.

In developing material cost, reference was made to a
listing of ships scheduled for conversion to Navy distillate
fuel [NAVY DEPT, MAY 1971]. This document was used because
it reflects, with respect to numbers and hull types, the
ships expected to remain in service for a period of time
justifying their conversion to distillate fuel. This yard-
stick is equally applicable to the installation of the SCFS.
A parametric approach will be used in developing cost figures
and prices will be inserted in the total cost formulas
developed. Table 8-3 is a listing of the parameters
utilized and their meanings.

The costs for the INDIRECT and DIRECT approach are cal-
culated by applying the appropriate formula below.

$$TC_{IND} = \sum_i K_i \, [N_i(C_I+C_{II}) + C_{III} + L] \qquad (1)$$

$$TC_{DIR} = N_pP + \sum_i K_i \, [S_i(C_I + C_{II}) + C_{III} + L] \qquad (2)$$

The values for the parameters K_i and N_i are summarized in
Table 8-4. It is to be noted that in some cases N_i is a
relatively small number since on these particular classes
of ships, the overflow tank concept discussed previously
is already employed.

The cost parameters C_I, C_{II}, C_{III}, L and P are listed
in Table 8-5 along with the source from which these

TABLE 8-3

Parameter Definitions

PARAMETER SYMBOL	DEFINITION
C_I	Cost per tank for Subsystem I of SCFS concept.
C_{II}	Cost per tank for Subsystem II of SCFS concept.
C_{III}	Cost per ship for Subsystem III of SCFS concept.
L	Labor cost (GEMS consultation).
N_i	Number of fuel tanks per ship of a specified class (i) requiring level indication.
K_i	Number of ships of specified class (i) receiving SCFS installation.
P	Cost per ship of piping modifications.
N_p	Number of ships requiring piping modifications.
TC_{IND}	Total cost INDIRECT approach.
TC_{DIR}	Total cost DIRECT approach.
S_i	Number of proposed/present tanks overflowing overboard per ship for specified class (i).

TABLE 8-4

Listing of Parameters K_i and N_i

SHIP CLASS (i)	K_i	N_i
DLG-6	10	23
*DLG-16	9	12
*DLG-26	9	12
DD-710	83	23
DDG-35	2	28
DDG-31	4	19
DDG-2	23	16
DEG-1	6	17
DE-1014	1	15
DE-1015	1	13
DE-1021	2	15
**DE-1033	4	15
DE-1037	2	21
DE-1040	12	16
*DE-1052	26	6
*CG-10	3	20
*CLG-4	4	18

*Ship classes presently employing overflow tank concept.
**Not planned for NDF conversion. Diesel driven ships.

TABLE 8-5

Cost Parameters

PARAMETER	VALUE (dollars)	SOURCE(S)
C_I	1300^1	1. Actual equipment cost figures for USS ALBERT DAVID (DE-1050) provided by GEMS (personal correspondence). 2. NAVSHIPSYSCOM ltr 9550 Ser 144-044, 13 July 1971. 3. NAVSECPHILADIV ltr 9480 Ser 1834, 9 November 1971.
C_{II}	575	Hunters Point Naval Shipyard, 18 February 1972.
C_{III}	575	Hunters Point Naval Shipyard, 18 February 1972.
L	160	GEMS figures for one day meeting during USS ALBERT DAVID (DE-1050) installation (personal correspondence).
P	$13,400^2$	NAVSECPHILADIV ltr 9480 Ser 1306, 22 November 1971.

[1]Computed by averaging the values for this item given in the three sources listed.

[2]This figure includes both material and shipyard labor costs.

parameters were derived. The parameter S_i is taken as 5[7] for those ships classes not already employing the overflow tank procedure [NAVSECPHILADIV ltr 9480 Ser 1306, 22 November 1971] and as N_i on ship classes having overflow tanks.[8] The parameter N_p is derived by subtracting the number of ships having overflow tanks from the total number of ships considered in this analysis (ΣK_i).

The results of these calculations are:

$$TC_{IND} = \$6,244,395$$

$$TC_{DIR} = \$4,650,525$$

This is a surprising result in that, apparently, this is one instance where piping modifications are economically more desirable.[9] The main cost factor contributing to the lower TC_{DIR} is P and, unfortunately, this is the least accurate figure in the analysis due to the fact that it was formulated for a short hull destroyer of the DD-692 class and has been used for all destroyer types in this report. However, with respect to fuel tanks, the difference between a short hull destroyer and larger destroyers is the presence of a third grouping of fuel tanks amidships on the larger

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[7]This figure includes two overflow tanks and three contaminated oil tanks and is considered realistic for those ships that require this piping modification since most destroyers have only two contaminated oil tanks but three fuel tank groupings.

[8]These ship classes are marked with an asterisk in Table 8-4.

[9]As opposed to the situation encountered in Chapter 3, Section II.

destroyers. One would then expect that the value of P would not be more than one third higher than the figure shown.[10] If P is assumed to be $18,000, then the adjusted total cost for the DIRECT approach would be:

$$TC_{DIR(ADJUSTED)} = \$5,340,525.$$

Again, the DIRECT approach is the least expensive of the two proposed procedures.

V. CONCLUSIONS AND RECOMMENDATIONS

The causes of oil spills during fuel movement evolutions have been categorized for all Navy ships and, in particular, destroyer type vessels. It is known that 77.9% of these spills for all Navy ships and 91.1% for destroyers are attributable to either inadequate INDICATION or CONTROL during the evolution. To eliminate these problems a SHIPBOARD CENTRAL FUELING STATION is proposed to provide accurate local and remote tank level indication and to provide a monitor with the ability to stop the fuel transfer evolution at a remote, centrally located, monitoring station if an emergency situation develops.

Two alternative methods of implementing this proposal were considered. Of the two, it has been shown that the DIRECT approach to the oil spill problem is the most

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[10] Phone conversation with NAVSECPHILADIV representative supports this assumption.

advantageous from both an engineering and economic stand-point. While the piping modifications required must be accomplished in a shipyard, this could be accomplished during the conversion of the ship to distillate fuel. In addition, this would greatly reduce the work that would be required of ship's force to install the large number of gauges, transmitters, and cabling characteristic of the INDIRECT approach. The implementation of the DIRECT approach on ships of the entire Cruiser-Destroyer Force would require the expenditure of approximately 5.5 million dollars.

The following action, which is projected to eliminate 90% of the causes of destroyer oil spills during fuel movement evolutions, is recommended:

1. Reduce the number of fuel oil tanks overflowing overboard to a minimum by appropriate piping modifications as discussed. This work should be accomplished in a shipyard.

2. Install all three Subsystems of the proposed Shipboard Central Fueling Station concept. Subsystems I and II, local had remote level indication, are to be accomplished on those fuel oil tanks which overflow overboard after Recommendation 1 is implemented.

3. Elevate the reduction of fuel tank oil spills to the level of a program in itself and allocate funds specifically earmarked for the implementation of Recommendations 1 and 2.

4. Ensure that all new construction vessels are constructed with a Shipboard Central Fueling Station, and all its component subsystems, and employ the overflow tank concept.

It is to be emphasized that this study was directed toward one specific type of vessel, the destroyer, in order that the procedure could be clearly illustrated. A similar analysis should be conducted for all types of naval vessels.

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CHAPTER NINE

ANALYSIS OF THE EFFECTS ON OIL SPILLS OF FUEL POLICY CHANGES
AND THE ADDITION OF ANOTHER FUEL PIER WITH THE
AID OF A COMPUTER SIMULATION MODEL

LCDR S. K. Laabs and LCDR T. L. Bowman

Abstract: A method of developing a general model of the oil
spill process (prescriptive and/or descriptive) is presented,
along with a discussion of its possible uses and benefits.
A limited simulation model is developed and utilized in
examining the effects of two of the variables of the general
model: 1) refueling policies, and 2) fuel pier/YO utiliza-
tion.
    Two changes are recommended that should significantly
reduce the number of oil spills in San Diego. One: reduc-
ing the maximum allowable on-board fuel level and the minimum
permissible level concurrently, and two: constructing an
additional fuel pier to be utilized to the maximum extent
upon completion, which will provide for the elimination of
all but one YO. It is also shown that the second concept
is economically justifiable independent of its effect on
oil spills.

I.   MODELLING THE OIL SPILL PROCESS

A general descriptive and/or prescriptive model of the

process underlying Navy oil spills could be extremely bene-

ficial in understanding and alleviating the oil spill

problem. This general model could provide for the predic-

tion of Navy oil spills and facilitate the analysis of the

effects of the variables in the process. Such a model would

include all significant causal-effect relationships; some of

the major variables of which would be: 1) the number and

types of ships in port, 2) refueling policies, 3) fuel

pier/YO utilization, 4) methods of fuel indication and control

(see Chapter Eight), and 5) time (see Chapter Seven). Several changes in the levels of the variables have been recommended in the past [Putman, 1970, NMMAC Pacific, 1970] with predictions that the changes would reduce the number of oil spills that occur.

It should be pointed out that there exists a great deal of interdependence among these variables. For example, if the maximum allowable fuel percentage on board is lowered while the minimum level is held constant, the number of oil spills due to overfilling tanks could be reduced. However, the number of refuelings would increase because of the decreasing length of time between refuelings, which would likely increase the number of oil spills due to other causes. The latter effect should be smaller than the former, so that the number of oil spills should decrease, but not by as much as might first be expected. This demonstrates the complexity of the oil spill problem. It is this complexity and the lack of information that makes simulation a most appropriate approach.

It is shown in this chapter that it is not unreasonable to assume that oil spills have a Poisson distribution, and it is expected that the type of distribution will not change in the future. The parameter λ of the Poisson distribution is, however, expected to change as the variables causing oil spills change. For example, an equation for λ might be of the form: $\lambda(\tau) = f(\underline{V})$ where $\underline{V}$ is a vector with some components being the variables mentioned above, and τ indicates

a time dependency. Using this equation as a model for λ, the effects of the variables could be independently or jointly examined. The following example demonstrates the possible effects on λ of varying some of the variables.

EXAMPLE. Varying the maximum allowable fuel tank level would be expected to affect λ as shown in Figure 9-1 (solid curve). However, varying the maximum allowable fuel tank level and the minimum prescribed fuel level concurrently would presumably affect λ as shown in Figure 9-2 (solid curve). The curves were determined through the following steps (see page 263, FY-70 data; 141 oil spills, λ = .386):
1) the number of oil spills due to overfilled tanks is approximately 118, which accounts for 84 percent of λ or .325. By lowering the maximum fuel tank level, the number of spills due to overfilled tanks decreases. There is very little change in λ at first, in lowering the maximum level from 100 to 95 percent, but after some point the number approaches, but never reaches, zero because of human error and equipment problems. This effect is shown by the dotted curves in Figures 9-1 and 9-2. In Figure 9-2 it is assumed that the minimum fuel level slides 15 percent below the maximum until the maximum level reaches 65 percent, then the minimum level remains fixed at 50 percent.
2) The number of spills due to causes other than overfilled tanks is approximately 23, which accounts for 16 percent of λ or .061. This number should remain approximately constant until the maximum percentage of usable fuel on board
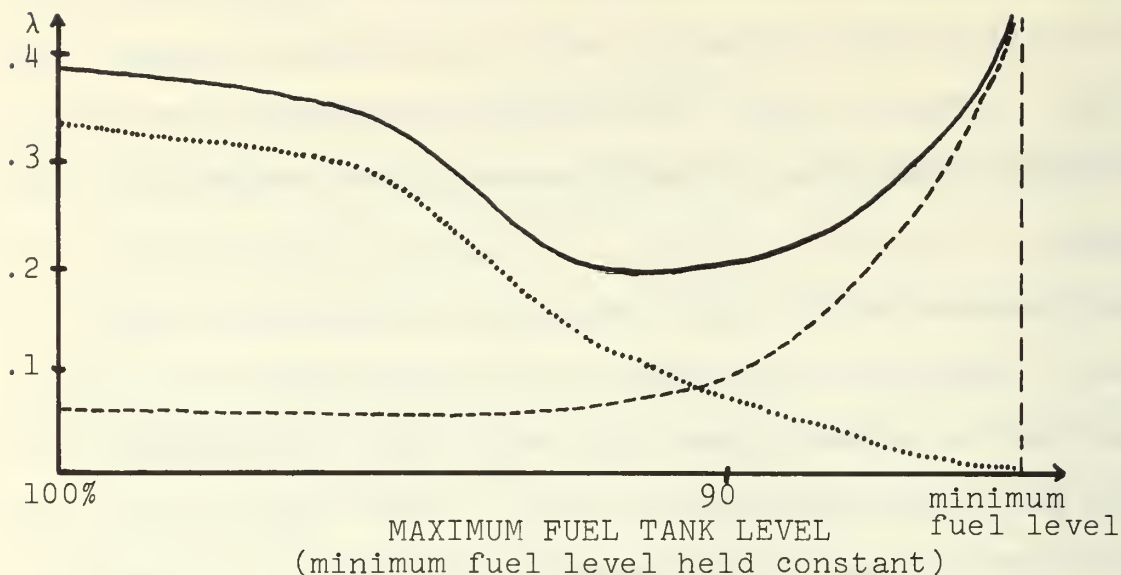
Figure 9-1. Effect on λ of Varying the Maximum Fuel Tank
Level While Holding the Minimum Level Constant. (λ = rate
of oil spills = mean number of oil spills/time; here,
time = 1 day. Present average minimum fuel level is
85%.) ..... effect on λ of overfilled tanks. -----
effect on λ of causes of oil spills other than over-
filled tanks.)
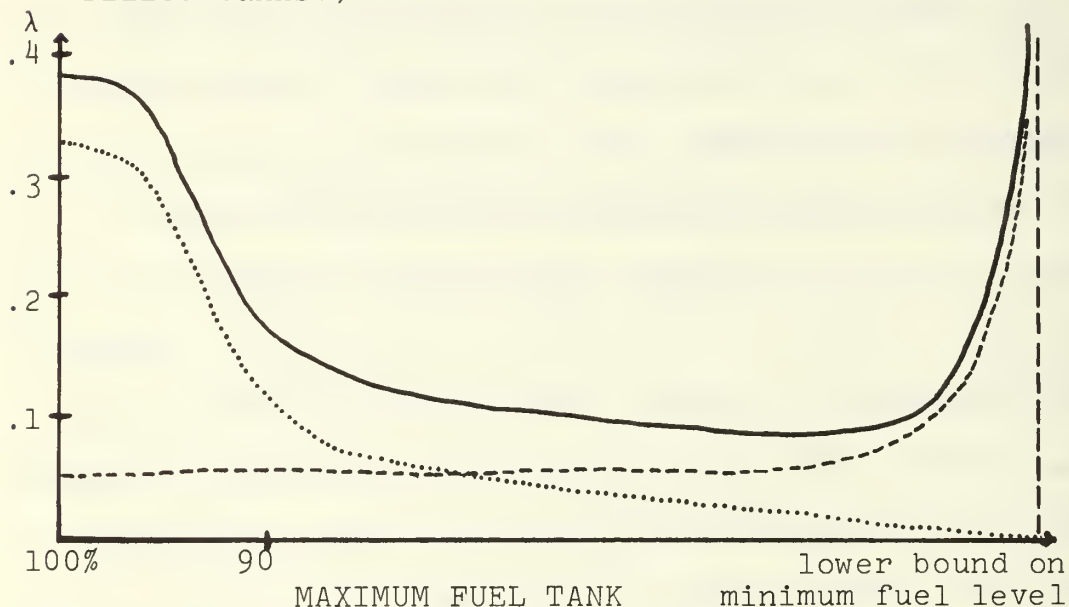
Figure 9-2. Effect on λ of Varying the Maximum Fuel Tank
Level While Varying the Minimum Fuel Tank Level. (It
is assumed that the difference between maximum level
and minimum level is constant until the minimum level
reaches its lower bound, i.e. 50%, then the minimum
level is constant.)

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(difference between the minimum and maximum levels) decreases to a point where the number of ship refuelings is substantially increased. Because of the increase in refuelings, the number of oil spills due to other causes should increase. This occurs slowly at first and then sharply as the number of refuelings becomes very large. This is shown by the dashed curves in Figures 9-1 and 9-2.

3) The solid λ curves in the figures are merely the sums of the dotted λ curves (due to overfilled tanks) and the dashed λ curves (due to other causes).

Due to the complexity of the problem, the development of a general model would require large quantities of carefully recorded data. The data presently available is insufficient for this purpose, however, it was sufficient for the development of a limited model, which is used in this chapter to examine two of the significant variables: 1) refueling policies, and 2) fuel pier/YO utilization. The model, given a λ, generates the expected number of oil spills and the expected clean up costs.

In developing the limited model, it was assumed that the generation of oil spills in San Diego Harbor is a Poisson process because, from the data available, it appeared that:

1. the number of spills during any interval of time, $\Delta t'$, depends only on the length of the interval (number of spills = $\lambda'\Delta t'$).

2. the spills occurring during non-overlapping time intervals are independent random variables.

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3. the probability of more than one spill in a small

   time interval, $\Delta t'$, is negligible compared to the

   probability of one spill in interval $\Delta t'$ (this holds

   for $\Delta t'$ in the range of 1 second to 12 hours) [Larson,

   p. 121, 1969].

Data from logs kept by the Public Works Center and the

11th Naval District was used to estimate λ and to examine

the assumptions about the distribution of oil spills. For

N days, the following procedure was employed to estimate the

Poisson parameter λ. Letting N_k = number of times k spills

occurred, then $N = N_0 + N_1 + N_2 \ldots + N_k$ and the total

number of spills, $T = N_1 + 2N_2 + \ldots + kN_k$. The available

data indicates that the maximum value of k equals 4 for the

process. The average number of spills per day is T/N, and

the best unbiased estimator of λ is $\hat{\lambda}$ = T/N = total number

of spills/total number of days observed.

The most complete logs appeared to be those for Fiscal

Year 1970 (actually 1 June 1969 - 30 May 1970), therefore,

FY'70 was used as the base year. The next most complete

logs were for FY'71 and FY'67.

It was assumed that spills occurring on weekdays and

spills occurring on weekends are independent Poisson proces-

ses. Here, time was divided into discrete intervals of 1

day = 24 hours. From the data, maximum likelihood estimators

[Larson, pp. 223-225, 1969] for the λ's were computed as

follows:

```
FY'70 total   = 141/365 = .386
FY'71 total   = 152/365 = .420
FY'67 total   = 104/365 = .285
FY'70 weekend =  15/106 = .143
FY'70 weekday = 126/260 = .485
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The Kolmogorov-Smirnov Test [Ostle, pp. 471-472, 1964] of goodness of fit was used to test the hypotheses that oil spills during FY'67, '70 and '71 were Poisson distributed (λ = .386) and that the λ's for FY'67, '70, and '71 were essentially equal. The data for weekends (λ = .143) and weekdays (λ = .485) for FY'70 were also tested for fit as Poisson distributions. All tests indicated that the hypotheses could not be rejected at the 1 percent significance level. Table 9-1 summarizes the results.

Because of the desired extensive use, the predictive nature, and possible future utilization, a computer simulation of the limited model was developed. The model receives as inputs the λ's for weekdays and weekends. Using these λ's, simulated oil spills are generated for each of 365 days of the year. Each of the 365 days is then checked to determine ship type responsibility for the spills. Then clean-up costs are calculated by ship type and total. In Chapter Seven a periodic effect is shown to exist over 12-month cycles. Since 1 year is the only time interval investigated, the periodicity effect was disregarded.

TABLE 9-1

Results of Kolmogorov-Smirnov Hypotheses Tests

NULL HYPOTHESIS	RESULT	REMARKS
FY'70 oil spills are distributed Poisson (.386)	$D = \max \|F(x) - S_n(x)\|$ $= .036 < 1.63/\sqrt{365}$ $= .085$	Hypothesis may not be rejected at the 1% significance level
FY'71 oil spills are distributed Poisson (.386)	$D = \max \|F(x) - S_n(x)\|$ $= .023 < 1.63/\sqrt{365}$ $= .085$	Hypothesis may not be rejected at the 1% significance level
FY'67 oil spills are distributed Poisson (.386)	$D = \max \|F(x) - S_n(x)\|$ $= .082 < 1.63/\sqrt{365}$ $= .085$	Hypothesis may not be rejected at the 1% significance level
FY'70 weekday oil spills are distributed Poisson (.485)	$D = \max \|F(x) - S_n(x)\|$ $= .030 < 1.63/\sqrt{260}$ $= .101$	Hypothesis may not be rejected at the 1% significance level
FY'70 weekend oil spills are distributed Poisson (1.43)	$D = \max \|F(x) - S_n(x)\|$ $= .009 < 1.63/\sqrt{105}$ $= .159$	Hypothesis may not be rejected at the 1% significance level

Table 9-2 shows the costs[1] and spill occurrence probabilities that are used in the model. These probabilities and costs are based on five years of data from 11[th] Naval District logs in San Diego. The probability of spill column gives the probabilities that given an oil spill, that type of ship was responsible, or it is the percentage of the oil spills in a year that are expected to be attributed to the different types of ships. There are some minor differences between the figures presented in this table and those presented in Chapter Seven. This is due to a slightly different classification of the smaller contributors. This classification was obtained from the more complete data that was developed for Fiscal Year 1970 by an extensive amount of cross-checking of several different sources of data for the same period of time.

There was a very large number of spills that could not be associated with any specific type of ship; therefore, it was assumed that these unknowns had the same distribution as the type ships in the Table 9-2. Oiler spills were associated with the functioning of the ship's engineering plant, and not with their refueling capabilities. Sub tender spills when identified had no associated cost, leaving us to assume (noting the location of the sub piers) that the oil was allowed to go out to sea on the tide.

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[1]Cost figures here represent only the civilian contracted clean-up costs because they were the only costs that could be connected with specific spills. There are many other "costs" which are extremely difficult, if not impossible, to measure such as environmental damage and civilian indignation.

TABLE 9-2

Oil Spill Occurrence Probability and Average
Clean-up Cost by Ship Type

TYPE SHIP	PROBABILITY OF SPILL	AVERAGE COST PER SPILL[2] (dollars)
Destroyer	.458	332.72
Amphibious Ships	.063	427.25
Cruisers	.071	221.68
Carriers	.145	532.67
Destroyer Tenders	.063	1381.26
Sub Tenders	.038	------
Oilers	.041	390.66
Shore Facilities	.021	458.09
Donuts	.064	443.13
Other Ships	.036	241.38

In summary, a simulation model was developed from 1) the
concept of a general model of the overall process of oil
spills, and 2) the fact that the data appears to satisfy the
assumptions of the Poisson process. This model is utilized
in the next two sections to examine a) changes in fuel level
policies, and b) fuel pier/YO utilization. The possible

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[2] It should be noted that over ninety percent of the cost
data used was for the old acceptable method of dispersion
instead of the new requirement of total clean-up which ap-
pears to have nearly tripled the costs. A direct cost ratio
could not be established, therefore costs are conservative,
possibly by as much as one third.

establishment of a management information system to be used
in the development of the general model is discussed in the
summary and recommendations section of this chapter.

II. CHANGING MINIMUM AND MAXIMUM ALLOWABLE
LEVELS OF FUEL ON BOARD

Besides physical equipment changes, there are other
things that can be done to affect the number of Navy oil
spills. Some of these are mentioned as major variables
in Section I, and others might be procedural changes,
stricter enforcement of requirements, exertion of pressure,
implementation of training, etc. An example of such a
change is related in a report from the California Department
of Fish and Game (DFG): "In the spring of 1967, Department
representatives met with Commander Cruiser-Destroyer Flotilla
Three concerning the high incidence of spills from ships
of his flotilla. . . . Once he became personally involved,
the flotilla's oil spills were reduced from one a week to
none in ten weeks. . ." [Putman, p. 8, 1970]. This example
also points out a possible major problem with the data on
oil spills--the suspicion that there is a significant
difference between "oil spills" and "reported oil spills."
It is indicated that as the penalties for oil spills increase
the desire to report spills greatly decreases.

Two policy changes will be examined here: 1) lowering
the minimum fuel percentage required on board and 2) extab-
lishing a maximum allowable level to which fuel tanks may

be filled. The computer simulation model described in the first part of this chapter was used to analyse the effects of making these policy changes. It should be pointed out that one could have treated the process deterministically by using expected values. However, the simulation model was utilized because 1) it was complete and functioning, and 2) it quickly and accurately computed the desired information. Prior to considering specific policy changes, it was decided to generate statistics for the entire range of possibilities using Fiscal Year 1970 as the base year. This was accomplished by calculating the $\hat{\lambda}$'s (weekday and weekend) for the different possible expected number of oil spills per year from 0 to 141 (in steps of 10), 141 being the number observed in the base year. The λ's were then used in the computer simulation model to obtain the number of spills (simulated average) and associated clean-up costs (simulated average). These results are displayed in Figure 9-3, showing the average simulated clean-up cost for each value of the expected number of spills.[3] The graph is nearly linear which agrees well with the regression analysis reported in Chapter Seven.

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[3]Ten computer runs were made for each value and then averaged. This brought the simulated mean number of oil spills to within 0.8 of the expected value and the simulated variance became less than the expected variance (6.7 < 7.2). The simulated variance of clean-up costs was 10.2.
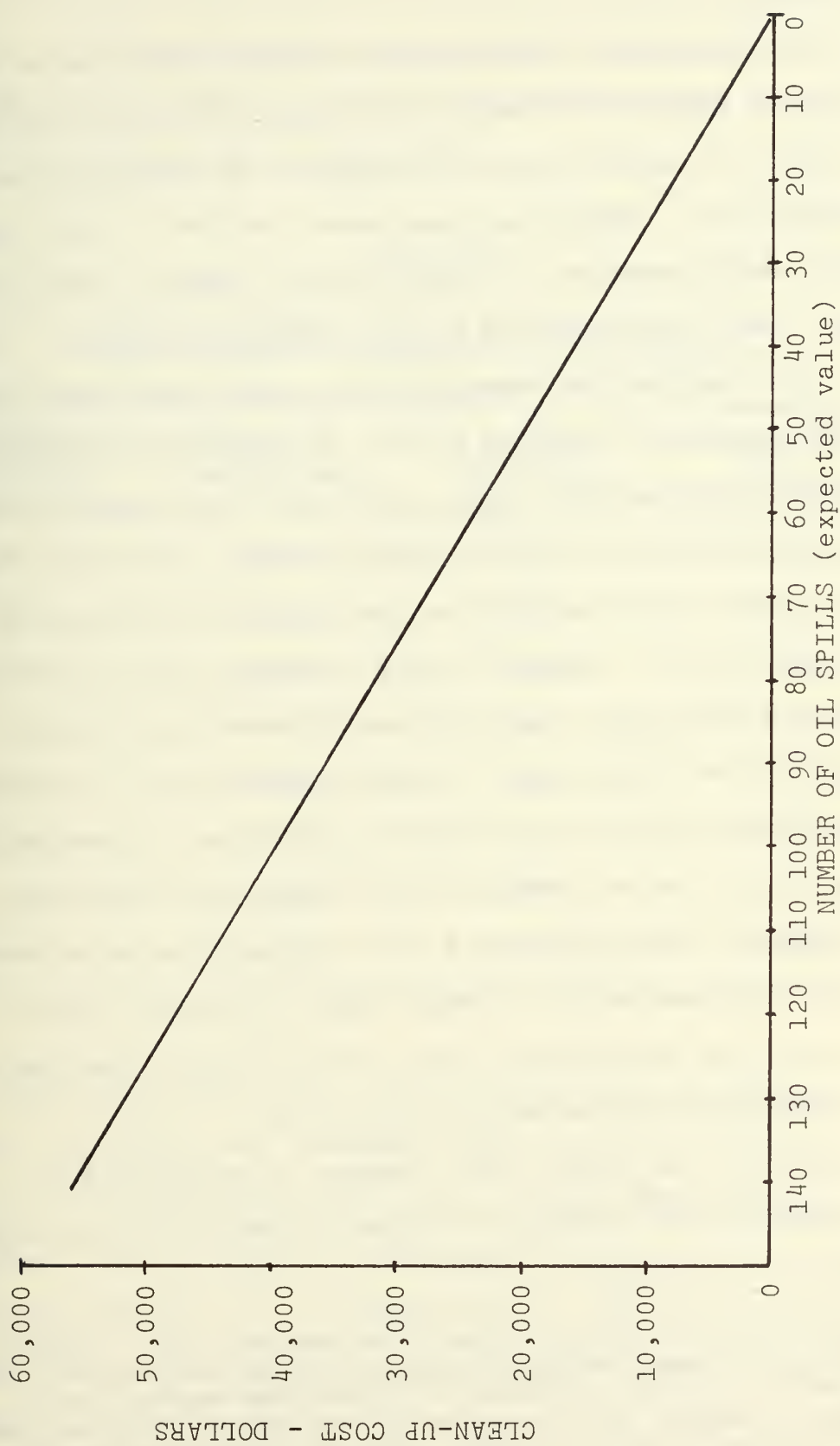
Figure 9-3. Total Clean-up Costs for Different Numbers of Yearly Oil Spills.

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A. POLICY 1

It was felt that one easy way to reduce the number of oil spills would be to reduce the number of refuelings and this could be accomplished by reducing the requirements for on-board fuel. Twenty-one destroyers in port in San Diego during 20-23 December, (10-DDs, 6-DEs, 2-DDGs, 2-DLGs, and 1-DEG), were questioned as to their refueling policy. It was found that on the average ships refuel when their level reaches 85 percent fuel on board. This is COMCRUDESPAC's standard, although the range was found to be 80-90 percent.

From examination of Port Services logs for Fiscal Year 1970 it was found that 1380 refuelings were conducted in San Diego Harbor. However, using available data, only 51 of these refuelings could be directly connected with oil spills.[4] From these data it would appear that 3.7 percent of refuelings result in oil spills, and that 36 percent of the oil spills were connected with refueling operations. This compares reasonably well with the California Department of Fish and Game report Putman, Table 5, 1970 , which indicates that 45 percent of the oil spills in Long Beach were connected with refueling operations.

Using the San Diego data, changes in on-board fuel requirements were examined. It was assumed that the percent

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[4]There were actually only 34 refuelings that could be directly connected with oil spills, but it was assumed that the number of spills related to refuelings among the 47 spills of unknown origin were distributed the same as among the 94 spills of known origin, thus 51 spills related to refueling operations.

of refuelings that result in spills is constant. Table 9-3
lists the expected number of oil spills connected with
refueling operations for each associated average percent
fuel on board prior to refueling.

TABLE 9-3

Expected Number of Oil Spills Associated
with Different Minimum Fuel Requirements

MINIMUM FUEL LEVEL (percent)	NUMBER OF REFUELINGS	NUMBER OF SPILLS	CLEAN-UP COST (dollars)
85	1380	51	20,700
80	1311	49	19,900
75	1245	46	18,700
70	1182	44	17,900
65	1123	42	17,100
60	1067	40	16,300
55	1013	38	15,500
50	963	36	14,700

Figure 9-4 shows the expected reduction in clean-up
costs associated with reducing the on-board fuel require-
ments to the indicated percentage. It is immediately
apparent that it would be necessary to reduce the on-board
fuel requirements to a drastically low level in order to
noticeably affect the oil spill clean-up costs. If the
requirement was reduced to 50 percent, the clean-up costs
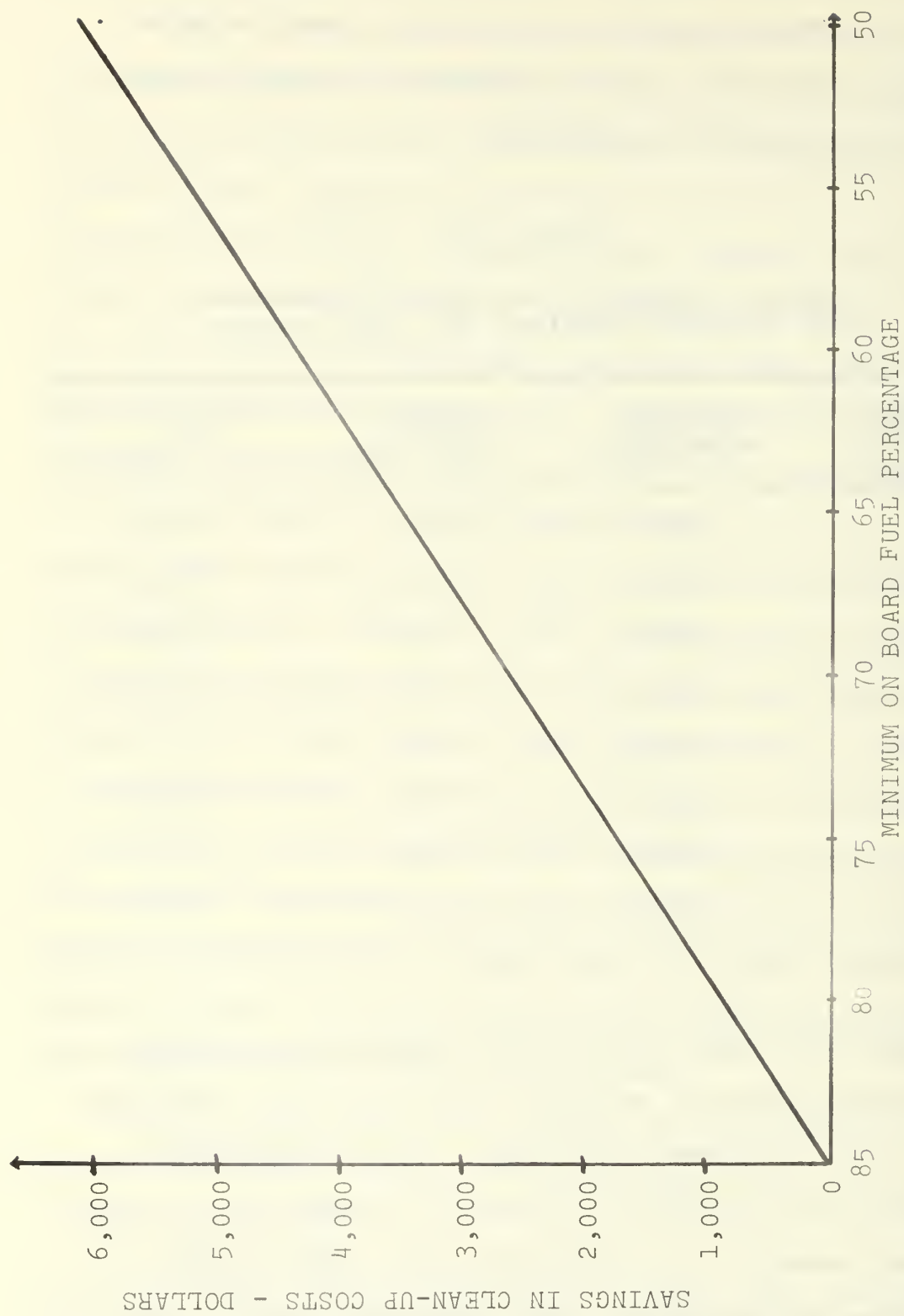
Figure 9-4. Clean-up Cost Savings for Different Minimum Fuel Levels.

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would only be reduced by 6,000 dollars, which is only an
11 percent reduction in clean-up costs.

B. POLICY 2

The second policy change to be examined is to establish
a maximum level to which a fuel tank may be filled. Data
from the California Department of Fish and Game Report
[Putman, Table 4, 1970] indicates that 84 percent of the oil
spills in Long Beach Harbor were a result of overfilled
tanks. Unfortunately, due to incomplete data collection
there is no data of this type available for San Diego Harbor.
From the 21 destroyers queried in San Diego it was found
that on the average, ships try to refuel to 98 percent on
board with a range of 90-100 percent. It is assumed that
the percentage of Navy oil spills, due to overfilled tanks,
in Long Beach Harbor is the same as in San Diego Harbor.
It would appear that if Navy ships were restricted from
filling fuel tanks above a maximum level of say 90 percent,
that the number of spills caused by overfilled tanks would
be significantly reduced.

Although it would be very difficult to analytically
determine the effect of this policy change, a range of
possibilities can be examined and experienced judgement
applied to arrive at the results. Figure 9-5 gives the
expected savings in oil spill clean-up costs versus the
possible effectiveness percentages from implementing the
policy.
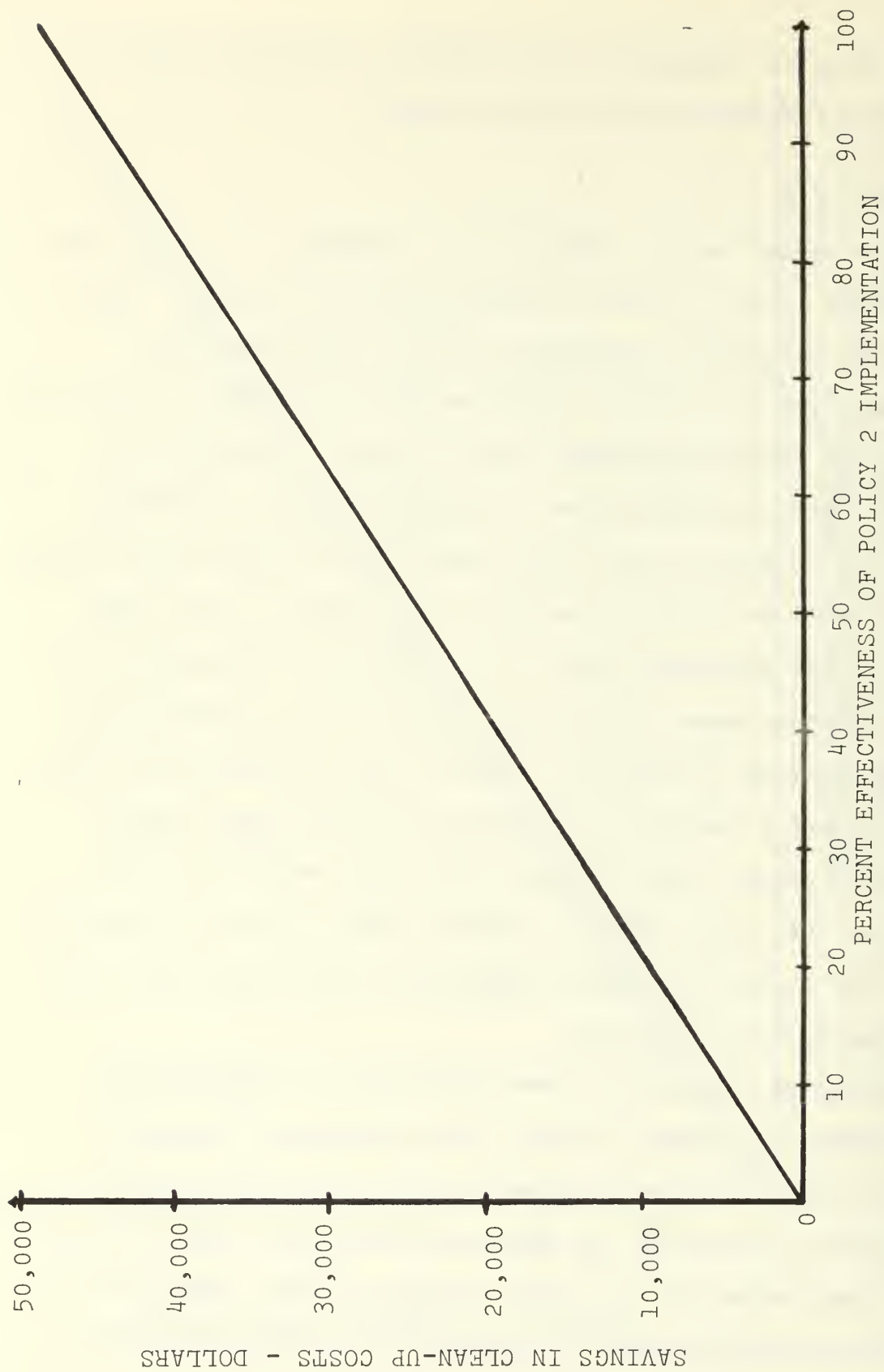
Figure 9-5. Clean-up Cost Savings for Different Levels of Effectiveness for Policy 2.

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It can be seen that even if the new policy is only 50 percent effective, clean-up costs will be reduced by approximately 45 percent. If the policy is 100 percent effective, that is if its implementation eliminates all overfilling of fuel oil tanks during refueling operations, intra-ship transfers, etc., then 84 percent of all oil spills will be eliminated along with 84 percent of the clean-up costs. The way to use the graph is first to determine subjectively the maximum level to which fuel tanks should be limited, then estimate the effectiveness of this policy, and finally go to the graph with this effectiveness percentage and obtain the expected savings in dollars for oil spill clean-up.

It is evident that it would be unwise to maintain the present standard of a minimum of eighty-five percent fuel on board and at the same time institute a policy that fuel tanks may not be filled above the ninety percent level. This would require a large increase in the number of ship refuelings which could result in an increase in spills related to refuelings, due primarily to causes other than overfilling tanks. Therefore, both of the policies discussed in this section should be implemented concurrently.

A lack of sensitivity of clean-up costs to lowering the minimum requirement for fuel on board indicates that the implementation of Policy 1 alone would not reduce clean-up costs as noticeably as it would ship's readiness. Policy 1 is therefore not recommended by itself. The Policy 2 change

appears to greatly affect clean-up costs, but as pointed
out earlier, for Policy 2 to be meaningful, Policy 1 must
be implemented concurrently. It is recommended that the
minimum on-board fuel requirement be reduced to 75 percent
and that ships be restricted from filling any fuel tank
above the 90 percent level (no more than 90 percent in any
tank for standard design ships, and no more than 50 percent
in the last tank for ships with fuel-water compensating
systems).

Since it is recommended that both Policies be implemented
concurrently, the differences between the current and
recommended maximum and minimum levels will not change sig-
nificantly. Therefore, the number of refuelings will remain
essentially constant and the reduction of oil spills from
causes other than overfilled tanks will be negligible. The
realized savings will result from a reduction in the number
of overfilled tanks, and it is estimated that this Policy 2
effect will be significant. If it is 75 percent effective,
clean-up costs could be reduced by approximately 36,000
dollars or 65 percent.

The proposed changes should reduce oil spills signifi-
cantly without noticeably affecting readiness. The effect
of selecting alternatives could be examined using the graphs
in Figures 9-4 and 9-5. It is important to recall that the
savings indicated on the graphs are conservative, and that
the actual savings may be 3 times as great (see footnote 2).
It should be noted that these recommendations are based on

the situation as it is now in San Diego, and that they may change as the situation is altered.

III. AN ADDITIONAL FUEL PIER AND CONCURRENT ELIMINATION OF YO'S

Naval ship fuel transfers at the fuel pier in San Diego result in a much lower spill rate per transfer than do transfers conducted with YO's. This statement is supported by the data from the logs kept at the Public Works Center and the 11[th] Naval District. The difference in rates is not believed to result from any great technical differences in the two modes of operation, but is believed to be due to the difference in the manning and readiness conditions existing on the serviced ships under the two conditions. Since a ship must get underway in order to be serviced at a fuel pier, it is essentially fully manned and in a complete state of fueling readiness when it conducts a fuel pier transfer. Often a much lower state of manning and readiness (such as provided by an engineering duty section) is the more likely situation during a YO fuel transfer.

A. PROPOSAL: AN ADDITIONAL FUEL PIER

According to the Department of Fish and Game-Long Beach (DFG) data, 48% of the Navy's oil spills can be attributed to fuel exchanges.[5] In San Diego for Fiscal Year '70, 1380

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[5]It was previously stated that 45% of the Navy's oil spills are due to refuelings. The 48% figure is for fuel

fuelings were conducted. Approximately one fourth of these, i.e., 317, were conducted at the fuel pier while the remainder were accomplished by YO's. Of the 317 fuel pier evolutions, not one oil spill was reported, however, the five year average 1966-1971 was 2.4 per year (PWC/11ND-Data). These facts suggest that the exclusive use of fuel piers for fuel exchanges could reduce the number of oil spills by up to 48%. Using the Public Works data for FY'70 and the fueling records of port services for this same period, 34 of the 141 spills for the year, roughly one fourth, can be associated with fuel exchanges. All are attributed to YO fuelings since there were none reported due to fuel pier exchanges that year. This percentage is approximately half that of the DFG data. The information in the PWC/11ND-Data however, is much less extensive or complete than that contained in the DGF report. It is therefore possible that up to 48% of all spills are due to intership fuel exchanges.

The above data led to investigating the proposed alternative of adding an additional fuel pier and adopting a policy of maximum use of the two fuel piers while simultaneously reducing YO operations. This alternative will be referred to as "The Additional Fuel Pier Concept."

The logical choice for the location of an additional fuel pier in San Diego is Pier J on North Island. This choice would complement the present fuel pier, since it is

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exchanges which include refuelings as well as bunkerings and offloading of fuel.

on the opposite side of the channel and is readily accessible.
It is large enough to accommodate two DD type ships at one
time and can also service the larger and less mobile deep-
draft ships. A complete economic analysis of the advantages
of a pipeline to North Island and the alteration of Pier J
will not be given here, only a modification of a previous
analysis. The basic analysis was done in conjunction with
MILCON Pipeline Project P-005[6] and subsequent economic re-
evaluations. The P-005 analysis showed that piping AVGAS
and black oil to North Island yields approximately 20%
annual return on the investment, i.e. a 20% reduction in
present operating costs. At this rate, it will pay for
itself in five to seven years due to the operating savings
resulting from the elimination of one YON and one YO.

   1. P-005 Economic Analysis

      A brief summary of the analysis initially presented
to C.O. United States Navy Fuel Supply Office by C.O. Naval
Supply Center San Diego is presented below. The analysis
will be modified by the predicted additional savings that
could be gained by adopting "The Additional Fuel Pier Concept."

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    [6]All documents concerning MILCON Pipeline Project P-005
could not be obtained. In this paper reference to MILCON
Project P-005 will mean any or all of the following
documents:
1. Commanding Officer, Naval Supply Center, San Diego, let-
    ter dated 6 September 1968 Serial 68/700 with Enclosures
    (1), (2), and (3).
2. SOWEST DIV, NAVFACENG COM Feasibility Study update of
    August 1968.
3. Commanding Officer, U.S. Navy Fuel Supply Office, Cameron
    Station Alexandria, letter dated 3 February 1970 (Ser
    Unk) with enclosure.

Annual Savings:

Eliminating YOG(N)-16	$ 38,354
Eliminating One YO	$176,043

Annual Costs:

Operating Black Oil Pipeline	$ 32,438
Operating Clean Oil Pipeline	$ 13,000
Total Annual Operating Costs	$ 45,438
Net Annual Operating Savings	$168,959[7]
Investment MILCON Project P-005	$925,000

2. Economic Analysis of P-005 as Modified by Additional Fuel Pier Concept

It is assumed that the pier modifications in the project do not include Pier J. Thus, including the operating and modification costs of an additional pier, we get the following P-005 modified costs:

Investments	$925,000
Pier J Modifications	$ 57,325
New Total	$982,325

Annual Operating Costs:

Project P-005	$ 45,438
Black Oil Pipeline	$ 32,438
New Total	$ 77,876

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[7] This is a conservative analysis as this is the lowest estimate of operating cost savings. SOWEST DIV, NAVFACENG COM in their August 1968 review indicated that even $197,700 annual savings is conservative.

These new costs may be over estimated as the entire P-005 package could not be obtained and may already include the investment and operating cost for Pier J.

Project P-005 savings result from eliminating one YO, one YON and their associated operating and handling costs. With the "Additional Fuel Pier Concept," it is expected that not one, but four, of the five presently operated YO/YOG's and one of the two YON's can be eliminated. Using normal working hours, two piers can service between four and eight ships per day. A maximum of two smaller type ships can be serviced at a time at each pier in both the morning and afternoon for a total of eight. One larger type ship can be serviced at each pier during each period for a total of four per day. These are conservative estimates as in a normal day it would take less than the allowed four hours per fueling, especially for the smaller vessels such as PGM's, ATF's and ATA's. Fueling by YO's would still be the most appropriate means to handle AR and AD fuelings due to the obvious disruption of industrial services that would result if they were required to get underway for each refueling. A similar argument justifies YO fueling of other large ships such as LPH's and CG's that cannot be berthed at North Island. Accordingly, only 67 of the 1380 FY'70 fuelings would still need YO servicing. Based on a 52-week year, five-day work week, an average combined servicing of just over five ships a day is necessary at the two piers. 1560 fuelings a year can be accommodated by a combined average

of six ships a day. It appears that the average number of
fuelings required per day will be between four and five
due to the reductions in the fleet size. This volume can
easily be accommodated by the use of two piers, probably
with no impairment to the ammunition supply services of
Pt. Loma pier.

Thus, "P-005 Modified," by dropping four instead of
one YO/YOG, results in a new net annual operating savings
of $664,650:

Elimination of 4-YO/YOG's	$704,172
1-YON	$ 38,354
New Total	$742,526
Net Annual Operating Savings	$742,526
Pier Operating Costs (Incl. Pier J)	$ 77,876
New Net Annual Savings	$664,650
Initial Investment	$982,325
Pay-off of "P-005 Modified"	1.48 years
Return on "P-005 Modified"	67 percent

B. ANALYSIS OF EFFECT OF "THE ADDITIONAL FUEL
    PIER CONCEPT" ON OIL SPILLS

Using FY'70 spill and cost data and using the five-year
average of 2.4 spills per year for all fuel pier transfers,
the effect of the additional pier was examined as a function
of the percent of the total number of spills due to fuel
exchanges. The expected range of benefits is 23 to 48
percent. The analysis results are:

HIGH	LOW

<table>
<tr><td align="center">HIGH</td><td align="center">LOW</td></tr>
<tr><td align="center">48% spills due to
fuel exchanges</td><td align="center">23% spills due to
fuel exchanges</td></tr>
</table>

48% x 141 spills = 68 spills   23% x 141 spills = 34 spills

Spills due to	−2.4	Spills due to	−2.4
Fuel Pier	——	Fuel Pier	——
Due to YO	= 65.6	Due to YO	= 31.6

This is one spill per 16.2   This is one spill per 33.7
YO fuelings   YO fuelings.

The 48% figure comes from the DFG report whereas the 23% comes from associating San Diego Port Services' fueling data with spill data for FY'70. Using 2.4 spills per year at the piers gives one spill per 132 pier fuelings. Since 67 fuelings would still be conducted by YO's, a net of 1313 fuel pier fuelings are necessary. Using the one spill to 132 pier fueling rate, the expected number of spills at the pier for 1313 fuelings is 9.95. In addition, we expect from 4.1 to 1.95 $\left(67 \times \frac{1}{16.1} \text{ to } 67 \times \frac{1}{33.7} \right)$ spills per year to occur while fueling the 67 "large immobile" ships by YO's.

The simulation model was used to obtain the projected spills and costs given in Table 9-4 and illustrated in Figures 9-6 and 9-7. The base case is FY'70 with 141 spills at a total cleanup cost of $55,702. The known number of spills due to fuel exchanges is 34 or 23% of the total spills. If only the number of spills for which the causes are known (94) is used, then 35% of the spills are due to exchanges. Again the DFG report states that 48% are due

TABLE 9-4

Projected Spills and Costs

PERCENTAGE OF TOTAL SPILLS ATTRIBUTABLE TO TRANSFER OPERATIONS	NUMBER OF SPILLS	COST (dollars)	SAVINGS* (dollars)	NUMBER OF SPILLS ELIMINATED
10	137	55,165	537	3
20	122	49,524	6,178	19
23	116	47,721	7,981	25
30	110	44,535	11,167	31
35	103	43,496	12,206	38
40	99	40,713	14,989	42
48	90	38,455	17,247	51
50	87	37,866	17,836	54
60	70	29,662	26,040	71
70	60	25,872	29,830	81
80	46	19,380	36,322	95
90	31	12,221	43,481	110
100	21	8,731	46,971	120

*Numerical value based on $55,702 for no reduction in spills.
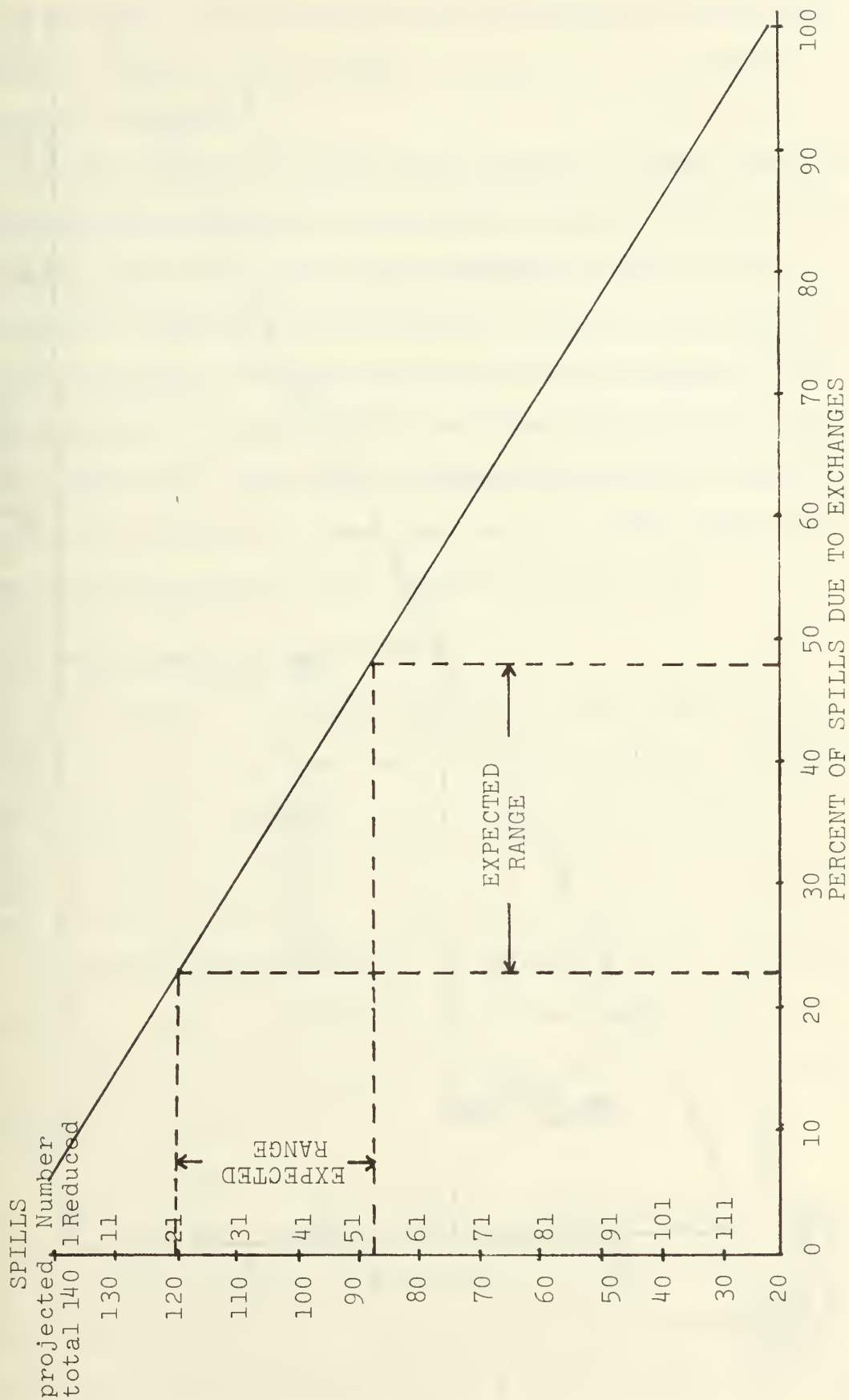
Figure 9-6. Total Projected and Eliminated Spills vs Percent of Spills Due to Exchanges.
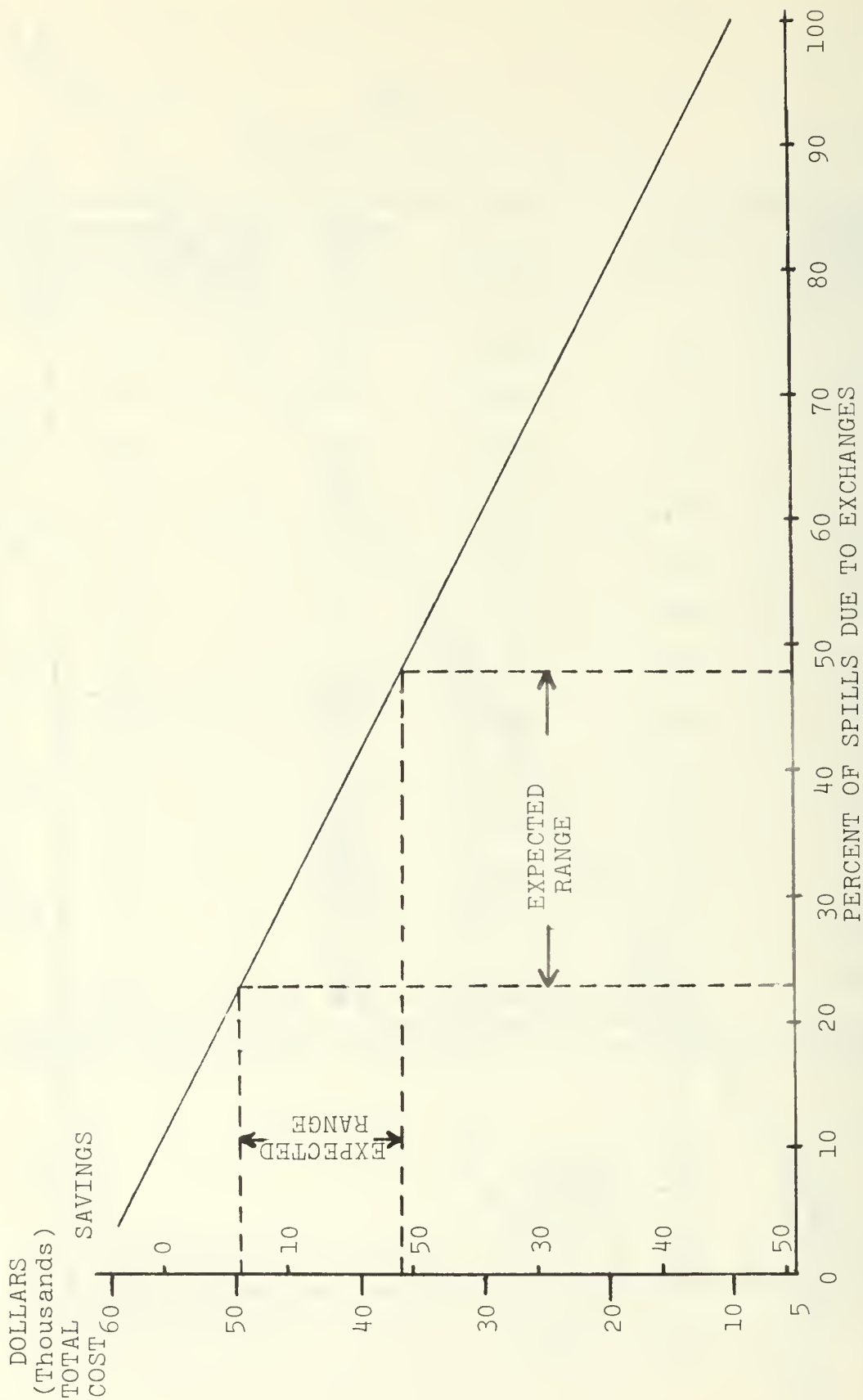
Figure 9-7. Projected Costs and Savings vs Percent of Spills Due to Exchanges.

to exchanges. These three points, defining the expected range, are shown on the graphs along with the even ten percentile points.[8]

If the cleanup cost per spill changes greatly from the five-year period used to obtain the average cost per spill factors used in the model, the projected costs will be incorrect. However, if as expected the cost of cleaning up spills increases, then the savings would be greater than shown and the projected total cost per year would be low. Projections less than 20% or greater than 50% are academic as they are beyond the data base and the curves may not be linear as displayed in the Figures 9-6 and 9-7.

C. OTHER CONSIDERATIONS

The concept of an additional fuel pier coupled with a policy of requiring that the pier be used almost exclusively is economically feasible as well as a very positive deterrent to Naval vessel oil pollution. There are other factors that must be considered in making the decision of whether to adopt this alternative and in formulating the subsequent policies. Some of these are considered below, but this is not intended to be an exhaustive list of all of the relevant decision variables.

1. Waste Oil

Waste oil is the subject of Chapter 6, but there are certain aspects of the waste oil problem that tie directly to fuel piers. Regardless of which concept is adopted, a large holding tank or a small holding tank with

an on-board separator, the contents of the tank must either
be piped off like sewage or collected periodically from
in-port ships. In either case, a large collection tank could
be provided at the pier with portable pumping equipment for
the ships to offload waste oil. This would reduce the need
for collection barges or of providing every ship with a
"holding tank manifold" at all times while in port.

2. Scheduling

It can be expected that there will be more requests
for pier fuelings on Mondays and Fridays due to weekly
operating schedules. This may cause some scheduling prob-
lems, but they can be overcome. Underway exercises can be
scheduled to allow for mid-week returns to port for fuel and
ammunition if necessary. The maximum use of AO, AOE and AOR
type ships while underway will also help.

3. Tugs

Sufficient tugs to maneuver ships at the fuel piers
may be a problem, but Pier J is an easily accessible pier
and LCM type amphibious craft could be used if necessary.

5. Clean Up and Control Equipment

Though positioning of containment and clean-up equip-
ment is treated in Chapter 11, the containment problem could
be reduced considerably by implementation of the Additional
Fuel Pier concept. Maximum utilization of the existing and
proposed new fuel piers and the high percentage of spills
due to fuel exchanges implies prepositioning equipment at
the fuel piers. By prepositioning the containment equipment,
it would be far more effective than having to deploy it to

each YO transfer spill at various and more congested berths at the Naval Station.

6. Fuel Types

Presently the YO/YON fueling capabilities are distributed among distillate, NSFO, and JP-5 fuels. By the time "P-005 Modified" can be completed, only the distillate capability should be necessary. Therefore, fuel type considerations do not affect the analysis. They must however, be considered in phasing out the YO/YONs if the project is completed prior to the completion of the distillate conversion.

"The Additional Fuel Pier Concept" is economically feasible. In addition, the concept will yield a considerable reduction in the occurrence of oil spills. It is therefore strongly recommended that this concept be adopted as soon as possible; that is, carry out MILCON Project P-005 "Modified" including mandatory use of the two fuel piers. Until completion of "P-005 Modified" the present fuel pier should be used to maximum capacity.

It is further recommended that a study on incorporation of solutions to the waste oil problem with fuel pier usage be examined (see Chapter Six).

IV.   SUMMARY AND RECOMMENDATIONS

In this chapter the following alternatives were examined:
1. Policy 1: Lowering the minimum fuel percentage
        required on board.

2.   Policy 2: Establishing a maximum allowable level
     to which fuel tanks may be filled.

3.   The Additional Fuel Pier Concept: Modifying MILCON
     Project P-005 and requiring the maximum utilization
     of the fuel piers while simultaneously eliminating
     YOs.

It was demonstrated that implementation of Policy 1 by
itself would not be very effective; but that concurrent imple-
mentation of Policies 1 and 2 will substantially reduce the
number of oil spills and associated clean-up costs. It
also was shown that completion of MILCON Project P-005
Modified is economically justified, and that fuel transfer
operations at fuel piers are much less prone to spills than
those conducted with YOs.

The major recommendations are that the U.S. Navy immedi-
ately institute Policy 1 and Policy 2 concurrently along
with utilization of the present fuel pier to the maximum
extent possible. It is further recommended that the levels
of Policy 1 and Policy 2 be as follows: Policy 1; lowering
the minimum fuel percentage required on board to 75 percent.
Policy 2; establishing 90 percent as the maximum allowable
level to which any fuel tank may be filled. Also Project
P-005 "modified" should be undertaken as soon as possible.

Immediate implementation of the above recommendations
should improve the Navy oil spill problems in San Diego
Harbor. Upon full implementation of "The Additional Fuel
Pier Concept" the number of Navy oil spills in San Diego
should decrease even further.

Finally, it is recommended that an overall data collection system be considered to collect data and monitor Navy oil spills in San Diego Harbor. This system should provide for 1) the identification of significant variables involved in the generation of oil spills, and 2) the monitoring of the effects of changes in the variables.

A management information system could be implemented to develop and update an overall simulation model. Justification of such a system is questionable at this time, as it is anticipated that the implementation of the changes recommended in this chapter and Chapter Eight will reduce the number of oil spills to an acceptable level.

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CHAPTER TEN

THE CONTAINMENT AND RECOVERY OF NAVY
OIL SPILLS - A FINANCIAL ANALYSIS

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Abstract: There are three basic alternatives by which the
Navy can provide for the containment and recovery of its oil
spills. These are: 1) a complete Navy in-house capability,
2) the exclusive use of contract services, and 3) a combin-
ation of Navy and contract services. Within each of these
alternatives there are several options.
     A financial analysis, including both quantitative and
qualitative factors, is conducted evaluating the alterna-
tives over a ten-year period. The results, showing the
total present value of each alternative, indicates that the
most desirable method of Navy oil spill cleanup is the use
of contract services. The most expensive method is a com-
plete Navy in-house capability.

I. INTRODUCTION

Various Navy directives are addressing the problem of

providing for the containment and recovery of Navy oil

spills. OPNAVINST 6240.3A, dated 14 September 1971, directs

that "A Navy in-house quick-response capability shall be

established at major naval complexes, under the coordination

of the Naval District Commandant, to contain and remove oil

pollution caused by operational type Navy oil spills." A

minor spill, as defined in OPNAVINST 6240.4, dated 2 March

1971, is one of less than 100 gallons, while a moderate spill

ranges from 100 to 10,000 gallons with a spill of greater

than 10,000 gallons being defined as a disaster.

These instructions recognize various alternative solutions to the problem of providing for an oil spill containment and recovery capability. However before the Navy, either on a service-wide or an individual station level, commits itself to one proposal or another the economics of the alternatives require thorough examination.

II. OBJECTIVE

The responsibility of the Navy for its oil spills goes without question. What is the most economical method for the discharge of this responsibility? What are the alternatives available to the Navy and their costs?

It is the objective of this study, through detailed financial analysis, to determine the most economically desirable method for the Navy to meet this responsibility. In addition to a quantitative analysis, the qualitative implications of the various alternatives will be discussed. This qualitative aspect is particularly important to this issue in view of the public demand for environmental protection.

III. DESCRIPTION OF ALTERNATIVES

Three basic alternatives will be analyzed in this study:

1. A complete Navy in-house capability.

2. Exclusive use of contract services.

3. A combination of Navy and contract services. Within these three basic alternatives several options are to be considered in order to provide as complete a coverage as possible.

The first alternative, an all-Navy capability, is directly related to the system proposed in the draft of Eleventh Naval District's Oil Spill Contingency Plan, COMELEVENINST 6240.1, DRAFT. This proposal calls for three teams of thirteen men each, outfitted in accordance with Annex B of the instruction. The teams, each of which is to be capable of handling oil spills of up to 1,000 gallons, are to be based at three different locations in San Diego Bay. With this organization it is assumed that the joint use of the teams for larger spills would preclude the need for supplemental contract services in all but the most disasterous situations.

The exclusive use of contract services assumes no Navy involvement in oil spill containment and recovery operations. The only exception permitted to this alternative is the need for a containment capability at Navy fueling piers. The recovery of oil due to spills at fueling piers would be part of the service contract.

The third alternative involves a combination of Navy and contract services. This combination may take any number of forms. For the purpose of this analysis only two possibilities are considered. The first involves the establishment of a Navy in-house capability to contain and recover

all oil spills of less than 100 gallons and the use of
contract services for larger spills. The second possi-
bility would require that the Navy develop a rapid-response
containment capability while utilizing contract services
for the recovery portion of the operation.

IV. METHODOLOGY

The planning horizon considered in this study is ten
years. This was chosen both for convenience and the fact
that by 1981 the frequency of oil spills is targeted to be
at a minimum. For purposes of discounting, the standard
Department of Defense rate of ten percent is used.

This study does not make any attempt to evaluate or
recommend a specific system or piece of equipment. The
items listed for the various alternatives represent planned
or intended configurations obtained from the activities
indicated. They are presented here for the purpose of cost
analysis and comparison of alternatives, not individual
evaluation.

All potential Navy costs and estimates of useful life
are based on the Navy's experience in this field. Where
such information is not available, industry averages are
used. While a large number of the specified equipment
acquisitions must be made through open purchase, there are
some items, such as small craft and vehicles, already in the
Navy inventory. For purposes of this study, such equipment

is costed at its direct procurement cost for the item in good operating condition, although not necessarily new.

It is recognized that some surplus equipment is available and that restoration costs may be less than procurement. At the Naval Station in San Diego a surplus LCM was converted for use in oil spill cleanup operations at a total cost of $700 [NCEL, 1971]. However pollution is a Navy-wide program, and to base it on the availability of surplus equipment is not considered advisable or practical. Instead, should surplus items be available, their use should be thought of as a program savings. The use of surplus equipment, though, generally results in larger maintenance costs and more frequent replacement.

The contract costs required for the analysis of the second alternative were obtained from past and current Navy contracts in San Diego. Future contract costs are expected to show an annual decrease reflecting the decrease in the number of spills.

The cost of the third alternative results from a combination of the other two alternatives. The configurations required for the two different options of this alternative are based on personal communications with contractors in San Diego and San Francisco and studies by Little (1969) and Walkup (1969).

This study does not include the costs for training Navy personnel and contract administration, nor the cost of working and storage spaces for a Navy capability. The effects of inflation are not considered in this study.

V. ANALYSIS OF ALTERNATIVES

The analysis of the individual alternatives is presented below. In addition to the quantitative analyses there are several qualitative factors related to one or more of the alternatives which must also be considered before a final decision may be reached. Because they are not quantifiable, a lesser importance is sometimes given them, although they may very well be the basis for the final decision. These factors, while they may affect more than one alternative, are discussed under the one to which they are most applicable.

A. A COMPLETE NAVY IN-HOUSE CAPABILITY

The cost of the Navy in-house capability is based on the proposal made by Eleventh Naval District for San Diego. Each of the required teams will be equipped as indicated in Table 10-1. The present value of operating each team for ten years is $823,340. Since three such teams are planned in San Diego the total present value of this alternative is $2,470,020.

The cost of the mechanical recovery device is based on the equipment currently in use at the San Diego Naval Station. The remaining unit costs represent industry averages [Little, 1969 and Gilmore, et.al., 1970]. The useful life of the various items is based on the estimates solicited by the author from Navy and civilian personnel experienced in this field. Initial procurement is assumed to occur at the beginning of year one while subsequent

TABLE 10-1

A Cost Summary for the In-house Containment
and Cleanup Capability

ITEM	QUANTITY	UNIT COST	USEFUL LIFE (yrs)	PRESENT VALUE
Oil Recovery Unit				
Converted LCM	1	$35,000	10	$35,000
NCEL Suction Head	3	150	2	1,600
Containment Boom	3,000 ft	7.75	2	82,400
Boom Boat	2	2,500	5	8,200
Boom Paravane	2 pr	700	5	2,300
Dispersant	55 gal	3.00	1	1,010
Sorbent Material				
Polyurethane Foam	400 lb	0.50	1	1,230
Truck	1	3,000	5	4,900
Miscellaneous				
Shovels, Rakes, etc.	-	500	1	3,000
Administrative				
Support	-	1,500	1	9,200
Personnel	13	8,130	1	650,000
Maintenance	-	4,000	1	24,500

Total Present Value of One Team - $823,340

The total present value of three such teams is $2,470,020.

replacement cash flows occur at the end of the replacement year.

As stated earlier, this particular system is designed to handle oil spills of up to 1,000 gallons. The requirement for three such systems is based on the current frequency and size of oil spills in San Diego Bay. A study made by Putnam (1970) in San Pedro, California indicates that only five percent of Navy oil spills were over 1,000 gallons in that port. Also the recommendations regarding the implementation of the on-board central fueling station concept and the construction of another fuel pier, presented in Chapters Eight and Nine of this present study, are designed to reduce both the size and frequency of oil spills in the future. Thus, the possibility of using only one team should be studied.

It is worthwhile to note that the personnel costs represent more than 75% of the total. The unit cost of $8,130 represents the average annual enlisted salary as computed from NAVCOMPT NOTE 7041 of 24 November 1971. This figure assumes that the personnel assigned to the oil spill cleanup teams could be released from the Navy if this capability did not exist.

Should this alternative be selected, the Navy will be unable to take full advantage of the potential cost savings generated by the current program to reduce oil spills. Assume for a moment that the Navy capability is the only one available to a Naval Station; there are no contract services available. This capability must be of sufficient

size to handle any expected spill. As long as the possi-
bility of a large spill exists, the capability to clean it
up must exist.

The assumption that the Navy capability would be the
only one available is a probable consequence of this alter-
native. Since a contractor has other uses for his equipment
besides the Navy contract, he can spread his costs among
these users. However, the Navy oil spill cleanup contract
may be the largest contract that he has, as is the case in
San Diego and San Francisco. Without this contract, the
contractor cannot justify the capital outlay required to
maintain an oil spill cleanup capability. This gives rise
to the possibility of leaving an area without a local
capability of cleaning up non-Navy spills.

The equipment used in cleanup operations today is
relatively unsophisticated and its effectiveness is in a
large part dependent upon the skill of the operator. Job
continuity is difficult to maintain in the Navy since
personnel are periodically rotated and may not necessarily
remain in Navy work of this specific type. A contractor
does not have a similar labor problem.

This alternative does provide the Navy with an indepen-
dent capability. Additional cost reductions may be effected
if a station can take advantage of the reduction in the
number of spills by reducing possible equipment redundancy.
This alternative would also provide the Navy with good
public relations material since it visibly indicates the

Navy's concern about the oil pollution problem and effort to minimize its impact.

B. EXCLUSIVE USE OF CONTRACT SERVICES

The cost of the annual contract services is based on the current contract the Navy has with Pepper Tank Cleaning Services in San Diego. This contract was awarded to cover the period 1 September 1971 through 31 August 1972 and has an estimated cost of $162,000. Although this cost is an approximation it does represent the contractor's best estimate of the cost of providing the required services based on the expected level of oil spill activity in San Diego Bay. This expected activity level was based on past oil spill data.

The contract requires that the contractor have the capability to handle single oil spills up to and possibly more than 50,000 gallons. General equipment guidelines are set down in the contract as well as the requirement for a response time of one hour, on a 24-hour basis, seven days a week. Payment is awarded monthly based on contract services provided per call.

It is assumed in this analysis that the number of oil spills will decline over the next ten years to 20% of their current level. For simplification this decline is assumed to be linear. The cost of contract services is directly related to the number of spills and is expected to decline in the same manner. Thus, using the ten percent discount rate for ten years results in a present value of the contract

services alternative of $686,300, as indicated in Table 10-2. This does not include the cost of administering the contract.

The Navy, under this alternative, is completely dependent upon the contractor. Special contract control is needed to insure the timeliness of response, maintenance of sufficient equipment inventory and standards of performance. Although failure in one of these areas may be grounds for cancellation of the contract, this is of little consolation after a spill occurs, especially if no competitor exists.

TABLE 10-2

Cost Summary of Contract Services

YEAR	PROJECTED COST	PRESENT VALUE*
1	$162,000	$153,400
2	147,600	126,500
3	133,200	103,200
4	118,800	83,500
5	104,400	66,400
6	90,000	51,900
7	75,600	40,000
8	61,200	28,900
9	46,800	20,000
10	32,400	12,500
	$972,000	$686,300

*Assumes equal monthly payments during each year.

The type of contract is of considerable importance.
It was mentioned earlier that the Navy's in-house capability
may result in a loss of civilian contractors in this field.
However a similar situation will arise in later years under
this alternative as contract costs are reduced. This is
assuming the contract payment continues on a per skill basis.
With the reduced frequency of spills resulting in lower
contract receipts, the contractor may again be unable to
justify the outlay required to maintain the necessary equip-
ment. Thus, some consideration should be given to the type
of contract and the manner of payment.

One possible solution is the payment of an annual fixed
fee to the contractor for providing the required services.
This contract would be awarded for a ten-year period at an
annual fee agreed upon by the Navy and the contractor. This
fee would be subject to change based on changes in applicable
price indices. The contractor would in turn provide unlimited
oil spill cleanup service to the Navy.

An appreciation for the effects of such a contract may
be gained by applying it to the contract alternative under
discussion. The average annual cost to the Navy is approx-
imately $100,000. This then represents a reasonable annual
payment on a ten year contract. The present value of such
an agreement is $675,900 which represents a favorable dif-
ference of $10,400 over the current contract alternative.

The contractor also benefits from such a proposal. He
is now able to plan ahead with more certainty. The fixed

contract payment greatly improves his credit position with the bank. He is thus in a position to more accurately and realistically budget for and maintain the capability required by the contract.

C. A COMBINATION OF NAVY AND CONTRACT SERVICES

This analysis presents two very different options with the intention of providing at least some basis for comparison with the other alternatives. The two options are: 1) an in-house Navy system capable of handling oil spills of up to 100 gallons, utilizing contract services for larger spills, and 2) the development of a Navy oil spill containment capability, utilizing contract services for the recovery of the oil.

The first option appears feasible and is in fact used at some Naval facilities. The equipment costs for such a capability are less than those shown in Table 10-1. However, as was the case before, the major cost would be the personnel.

Data taken from the study by Putnam (1970) indicates that approximately 67% of the Navy oil spills in San Pedro Bay from 1962 through 1969 were 100 gallons or less. This same percentage is assumed to be applicable to San Diego. It was then assumed that the contract costs to cleanup all spills over 100 gallons would be 33% of the present contract costs. Table 10-3 is a summary of the cost of this option which has a total present value of $1,221,682.

TABLE 10-3

A Cost Summary for a Joint Navy/Contractor Capability

ITEM	QUANTITY	UNIT COST	USEFUL LIFE (yrs)	PRESENT VALUE
Navy In-house Capability for Spills Less than 100 Gallons				
Oil Recovery Unit				
Mobile platform	1	$10,000	10	$10,000
NCEL Suction Head	2	150	2	1,100
Containment Boom	1,500 ft	7.75	2	41,200
Boom Boat	1	2,500	5	4,100
Boom Paravane	1 pr	750	5	1,100
Dispersant	55 gal	3.00	1	1,010
Sorbent Material				
Polyeurathane Foam	200 ft^3	0.50	1	614
Truck	1	3,000	5	4,900
Miscellaneous	–	500	2	1,770
Administrative Support	–	500	1	3,000
Personnel	5	8,130	1	250,000
Maintenance	–	2,000	1	12,300

Total Present Value of One Team - $331,094

The total present value of three such teams is $993,282.

YEAR	PROJECTED COSTS	PRESENT VALUE
Contract Costs for Spills Greater than 100 Gallons		
1	$54,000	$51,100
2	49,200	42,100
3	44,400	34,400
4	39,600	27,800
5	34,800	22,100
6	30,000	17,300
7	25,200	13,100
8	20,400	9,600
9	15,600	6,700
10	10,800	4,200
	$324,000	$228,400

The total system present value is $1,221,682.

The second option, a combined capability, envisions that the Navy develop and maintain a rapid response containment capability. This could take the form of rapidly deployable mechanical booms stored on the waterfront. This type of arrangement is employed at the Navy Fueling Depot in San Diego with the booms stored on large reels at the head of the pier. Another possible solution would be the installation of some fixed type of pneumatic boom around berthing areas.

This option permits the rapid containment of the oil spill, thus reducing the area covered and the time required for recovery by a contractor. In addition it would be expected that damage claims resulting from the spill would be reduced because of the smaller potential area coverage. This option also reduces the single most expensive item—personnel.

The analysis of this option required some estimate as to the potential contract cost reduction resulting from the Navy capability. From information in the current contract in San Diego, it was determined that the contract cost would be cut approximately 31% if the Navy took over the containment function. This assumed that contract labor costs overall would be reduced 40%. This result is consistent with a study by Arthur D. Little, Inc. (1969) which indicates that the containment costs for a 1,000 gallon spill were approximately 34% of the cleanup costs.

Therefore, an initial contract cost of $112,500 was
assumed, with the annual contract payments declining as
discussed earlier. The cost of the Navy containment system
is based on the use of mechanical booms. The total present
value of this option, summarized in Table 10-4, is $1,237,135.

One disadvantage to both of these options is the amount
of coordination required between the Navy and the contractor.
With the first option problems exist with underestimating
the spill size and overestimating the in-house capability
resulting in costly delay. On-scene coordination problems
could arise in the turnover of equipment and responsibility.
The problem of coordination is not, however, insurmountable,
as is evidenced in the many regional pollution control dis-
aster plans.

D. SUMMARY OF ANALYSIS

Table 10-5 is a summary of the costs of the various
alternatives and options considered in this analysis. The
cost represents the present value of the alternative for
ten years of operation, discounted at ten percent.

The major factor affecting these costs is the ability
of an alternative to realize the potential savings generated
by the Navy's reduction of oil spills. This is illustrated
in the schematic below which compares the trends of the
two cost extremes.

TABLE 10-4

A Cost Summary of the Navy Containment-
Contract Recovery Capability

ITEM	QUANTITY	UNIT COST	USEFUL LIFE (yrs)	PRESENT VALUE
Navy Containment System				
Containment Boom	5,000 ft	$7.75	2	$137,000
Boom Boat	2	2,500	5	8,200
Boom Paravane	2 pr	700	5	2,300
Personnel	2*	8,130	1	100,000
Maintenance	-	1,000	1	6,145

Total Present Value of One Team - $253,645

The total present value of three such teams is $760,645.

*This represents the additional personnel needed to augment
station personnel to perform this function.

YEAR	PROJECTED COSTS	PRESENT VALUE
Contract Costs for Oil Recovery		
1	$112,500	$106,500
2	102,500	88,000
3	92,500	71,800
4	82,500	57,900
5	72,500	46,100
6	62,500	36,000
7	52,500	27,300
8	42,500	20,000
9	32,500	13,900
10	22,500	3,700
	$675,000	$476,200

The total system present value is $1,237,135.

NUMBER OF SPILLS

COST OF IN-HOUSE
    CAPABILITY

                                                    1981

                        TIME
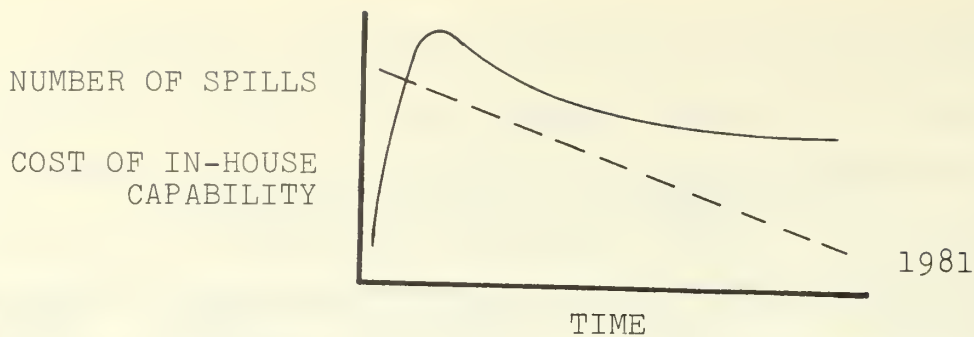
    The cost of the Navy in-house alternative, being

relatively insensitive to the number of spills, rises

sharply due to initial outfitting and remains high due

primarily to personnel costs. The cost of the contract

alternative is directly related to the number of spills

and thus declines at the same rate. Both alternatives

neglect any possible cost of living increases.

                        TABLE 10-5

                Summary of Cost Analysis

ALTERNATIVE/OPTION	COST
Exclusive use of contract services	
Fixed annual payment	$ 675,900
Per spill payment	686,300
One in-house Navy team	823,340
Navy cleanup spills less than 100 gallons	
contractor cleanup other spills	1,221,682
Navy contain spills, contractor cleanup	1,237,135
Navy in-house capability - three teams	2,470,020

VI. CONCLUSIONS

It is concluded from this study that wherever such services are available, the exclusive use of contract services be the method selected for the containment and recovery of Navy oil spills. This alternative is the most complementary to the Navy program to reduce spills because its costs are more directly related to the spill activity than those of the other alternatives considered.

It is also in the public interest that the Navy use contract services for oil spill cleanup. A contractor has costs similar to those of the Navy capability. However, he has several customers among whom he is able to spread his costs. Thus, by using contract services the Navy is helping to insure that a civilian capability exists not only to serve the Navy but the community as well.

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CHAPTER ELEVEN

LOCATION AND EQUIPMENT FOR OIL RECOVERY
TEAMS IN SAN DIEGO

LT Charles R. Murphy, Jr.

Abstract: The problem of how to minimize the effects of oil
spilled onto San Diego Bay is approached in two phases. The
first part of the report describes a linear analysis of data
from previous oil spills and evaluates the relative effec-
tiveness of recovery teams stationed at various Naval facil-
ities in the area based upon the expected distance they must
travel to a spill. It is concluded that the most cost-
effective deployment is one team at each of the Naval Sta-
tion, the Naval Air Station North Island and the Fuel Pier
as proposed by COMELEVENINST 6240.1 DRAFT. A survey of
current devices and techniques for control and recovery of
oil on the water is presented with particular attention to
those techniques appropriate for Naval activities in the San
Diego area. Specific recommendations are made concerning
the equipment and training emphasis to be alloted to each
recovery team.

I.   <u>PURPOSE AND APPROACH</u>

The purpose of this report is to determine the most

effective combination of equipment and its employment in

San Diego in order to minimize the effects of oil spilled

by Navy units onto San Diego Bay. This effort is based

upon the assumption that petroleum products will continue

to be released inadvertently onto the water despite Navy

efforts to prevent spills by procedural and technical

developments. It is assumed that most future spills will

be of lighter, more volatile products such as JP-5 and Navy

distillate rather than of heavier oils such as Navy Special

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Fuel Oil (NSFO). Disposal of the oil once it has been recovered from the water is not treated in this report.

The problem is approached in two distinct phases. In the first part of the report, a mathematical programming technique is applied to data from oil spills over the last five years in San Diego in order to determine the most effective locations at which oil recovery teams should be stationed. A survey of the current devices and techniques currently available for recovering and controlling oil on the water is described in the second part. Those devices and techniques which seem most appropriate for use in San Diego are selected.

The draft of the Commander Eleventh Naval District (COMELEVEN) Oil Spill Contingency Plan (COMELEVENINST 6240.1 Draft) was made available by members of his staff. The organization and currently available resources described in that plan were considered in what follows.

II.   ANALYSIS OF LOCATION OF RECOVERY TEAMS

The organization and location of oil spill recovery teams depend upon many factors; two of these are the frequency at which spills may be expected at a given location and the expected size of the spills. When this information is available, a mathematical program may be solved to determine the location at which the distance to the expected center of spills is a minimum. Such a program is based upon

the assumption that the time elapsed between a spill and initiation of collection efforts is proportional to the distance recovery teams must travel to the spill location. It is noted that the expected center of spills based upon frequency may not coincide with that based upon size of spills, so that decision-makers may have to select the factor which they consider most important.

The data discussed in Chapter Seven of this report concerning oil spills occurring in San Diego over a five year period was examined in order to determine the best allocation of recovery teams in San Diego. Since reliable data concerning the size of oil spills was not available, the assumption that cost of cleanup was proportional to size of spill was made. This was a major assumption and certain limitations must be noted. While cost of recovery is a function of the size of the spill, it is also a function of the time the spill remained on the water, the complexity of the area of the spill in terms of piers, ships, etc., and several other factors. Averaging the cost data over the five-year period does not account for the effects of inflation. Further, the likelihood that the contractor has a minimum cost independent of size of spill is not considered. Despite these weaknesses, the results of the analysis based upon the cost data closely paralleled those of the analysis based upon frequency data.

Based upon the existence of Naval facilities available for support, four locations were considered as potential

sites for recovery teams: Chollas Creek at the Naval

Station (NAVSTA), berth L at the Naval Air Station North

Island (NORIS), the Naval Electronics Laboratory (NEL)

pier at Fleet Training Group (FTG), and the Fuel pier (see

Appendix D). These sites were compared in order to deter-

mine their relative value as a recovery team base. The

distances used in the analysis were channel distances,

that is the distance from one point to another via navigable

water (water depth greater than twenty feet), rather than

Euclidean distances. Distances were taken from Coast and

Geodetic Survey Chart 5105 "North San Diego Bay."

Examination of both the frequency data and the cost data

revealed that the locations of oil spills which had occurred

could be grouped into seven clusters L_i, i = 1,...,7, which

accounted for over 95% of the spills reported. The largest

cluster in terms of both frequency and cost was the pier

area of the Naval Station. In order to determine a centroid,

or expected center of locations of spills for the cluster,

a reference line was drawn from the Northwest corner of the

mole pier to the seaward end of Pier 1 and all spills were

assumed to have occurred along this line. The distribution

of spills along this line was then analysed in order to find

the points x_1 and x_2 for which the following two expressions

are minimized:

frequency $\quad F_1(x) = \sum_{x \varepsilon L_1} |x-x_1| \, p(x)$

cost $\qquad\quad G_1(x) = \sum_{x \varepsilon L_1} |x-x_2| \, C(x)$

where   x   = distance in yards along line from mole pier
              to location of spill

         p(x) = relative frequency at which a spill occurred
              at distance x

         C(x) = total cost of cleanup of spills occurring at
              distance x

The numbers used in the analysis are given in Table 11-1.

In this case, x_1 and x_2 were found to be nearly coincident

at the end of Pier 4. This point was taken as the expected

center of spills in the Naval Station area and the channel

distance from it to each of the four potential bases was

measured.

The centroid for the NORIS cluster was determined in

two dimensions in order to take account of the spills which

had occurred at mooring buoys numbers 23 through 28. A

TABLE 11-1

Naval Station Centroid Data

LOCATION PIER	DISTANCE (yards) x	RELATIVE FREQUENCY p(x)	TOTAL COST (dollars) C(x)
1	2190	0.13	18087.23
2	1840	0.19	30407.08
3	1580	0.10	14417.83
4	1320	0.16	39218.18
5	1060	0.06	10679.23
6	800	0.19	24808.07
8	300	0.14	27516.20
mole	0	0.03	3224.50

reference point was chosen at 31°-42'-12.8"N, 117°-10'-27.2"W
and the distance North, y, and the distance West, x, measured
to the location of each spill. Iterative techniques were
used to determine the centroids (x_1,y_1) and (x_2,y_2) at which
the following expressions are minimized:

$$\text{frequency} \quad F_2(x,y) = \sum_{\substack{(x,y) \\ \varepsilon L_2}} \sqrt{(x-x_1)^2 + (y-y_1)^2} \; p(x,y)$$

$$\text{cost} \quad G_2(x,y) = \sum_{\substack{(x,y) \\ \varepsilon L_2}} \sqrt{(x-x_2)^2 + (y-y_2)^2} \; C(x,y)$$

where (x,y) = distance in yards from reference point to
spill location

   $p(x,y)$ = relative frequency at which a spill occurred
at point (x,y)

   $C(x,y)$ = total cost of cleanup of spills occurring
at point (x,y)

The data used in these expressions is given in Table 11-2.
The frequency centroid (x_1,y_1) was found to be at 31°-42'
-22.2"N, 117°-11'-11"W and the cost centroid (x_2,y_2) was
found to be at 31°-42'-19.5"N, 117°-11'-10.4"W. Since these
centroids are only about 100 yards apart (in the vicinity
of berth N), the distances from the proposed base sites to
the cost centroid were measured.

The third cluster (L_3) was determined to be the area
around the Navy Pier and the Broadway Pier. Since precise
spill location data was not available, the center of the
seaward end of the Navy Pier was taken to be the centroid.
As before, the distances from the centroid to each proposed
site were measured.

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TABLE 11-2

North Island Centroid Data

LOCATION BERTH/ BUOY	DISTANCE (yards)		RELATIVE FREQUENCY p(x,y)	TOTAL COST (dollars) C(x,y)
	x	y		
J/K	1400	1100	0.27	7162.92
L	1550	350	0.23	10050.16
M/N	1230	200	0.27	13269.25
O/P	700	50	0.16	23109.09
#24	850	1050	0.03	511.75
#28	0	350	0.04	614.90

The fourth cluster (L_4) occurred along the mooring buoys off Harbor Island, numbers 15 through 21. A reference line was drawn from buoy 15 to buoy 21 and distances measured along this line from buoy 21. In the same manner as that done for the Naval Station, a one-dimensional centroid was calculated (Table 11-3). Both the cost and frequency centroids were determined to be within 50 yards of buoy 19 and the distances were measured as before.

Precise spill location data was not available for the remaining clusters, L_5, L_6, and L_7, so that a centroid was assumed for each. The seaward end of the NEL pier was chosen as the centroid for spills occurring near FTG. At the Fuel Pier the center of the head of the T was designated the centroid. The seaward end of the submarine pier was selected as the centroid of spills in the area of Ballast Point. A summary of the clusters with the related centroids and frequency and cost weighting factors is given in Table 11-4.

TABLE 11-3

Harbor Island Buoy Centroid Data

LOCATION BUOY	DISTANCE (yards) x	RELATIVE FREQUENCY p(x)	TOTAL COST (dollars) C(x)
15	1800	0.04	0.00
16	1500	0.09	48.43
17	1200	0.13	1,010.29
18	900	0.13	606.45
19	600	0.26	770.74
20	300	0.22	442.29
21	0	0.13	875.13

TABLE 11-4

Summary of Cluster Data

CLUSTER NUMBER i	CLUSTER AREA	CENTROID	RELATIVE FREQUENCY $p(d_i)$	TOTAL COST (dollars) C_i
1	NAVSTA	Pier 4	0.67	168,358.00
2	NORIS	Berth N	0.18	54,718.00
3	H.I. Buoys	Buoy 19	0.04	3,753.00
4	Fuel Pier	Fuel Pier	0.02	7,045.00
5	Ballast Pt.	Sub. Pier	0.02	666.00
6	FTG	NEL Pier	0.01	831.00
7	Navy Pier	Navy Pier	0.01	3,015.00

The locations of the centroids and the proposed team sites are also noted on the diagram of San Diego Bay presented in Appendix D.

The data thus accumulated was used to evaluate two measures of effectiveness for each potential site and certain selected combinations of sites: the expected distance from the given site or combination of sites and the cost-distance product. Comparison of these two measures allows some consideration of the dichotomy discussed earlier in this section between frequency of spill and cost of cleanup (i.e., size of spill). The expected distance is given by

$$E[D] = \sum_{i=1}^{7} d_i \, p(d_i)$$

where d_i = channel distance from nearest site being considered to i^{th} cluster centroid

          $p(d_i)$ = relative frequency of spills which occurred in the i^{th} cluster

The cost-distance product, CD, was defined as the name implies:

$$CD = \sum_{i=1}^{7} d_i C_i$$

where C_i = total cost of cleanup of spills which occurred in the i^{th} cluster

A large number of possible basing combinations were possible from the four proposed sites; therefcre an assumption was made in order to reduce the amount of computation required. Since a large percentage (67%) of the reported

spills occurred at the Naval Station cluster as well as the
largest total cost figure, it was assumed that any basing
combination would include basing a team at the Naval Station.
The results of the analysis for the basing combinations
considered are given in Table 11-5.

TABLE 11-5

Comparison of Potential Recovery Team Stations

BASING SITE	EXPECTED DISTANCE (yards)	COST-DISTANCE PRODUCT (yard-dollars x 10^6)
Single Site Used:		
NAVSTA	3092	7.92
NORIS	4749	12.50
FTG	7735	19.50
Fuel Pier	9196	24.90
Two Sites Used:		
NAVSTA and NORIS	1469	3.32
NAVSTA and FTG	2005	5.15
NAVSTA and Fuel Pier	2457	6.35
Three Sites Used:		
NAVSTA, NORIS, Fuel Pier	1189	2.79
NAVSTA, FTG, Fuel Pier	1884	4.90
All Four Sites Used:	1156	2.77

III. RESULTS OF LOCATION ANALYSIS

The summary presented in Table 11-5 indicates that the
two measures of effectiveness chosen paralleled each other
for the most part. It should be noted that the time effect
discussed in Chapter Seven has been absorbed by considera-
tion of the data in the aggregate for the entire five year
period.

Both measures of effectiveness are at their best
(minimum) value when oil spill recovery teams are stationed
at all four locations considered. Such a disposition is
about three times as effective as deployment to the best
single location, the Naval Station. It was expected that
the Naval Station would be the best single location since
the greatest percentage of spills and the most expense
occurred there.

The overall effectiveness is improved by nearly a third
over that of a single team location when a second team is
based at NORIS. This conclusion also follows from the
magnitude of the frequency and cost factors. The expected
distance, as well as the cost-distance product, is reduced
by half again when a third team is based at the Fuel Pier.
This is the deployment currently planned by COMELEVENINST
6240.1 Draft. System effectiveness is improved by less
than 3% when a fourth team is deployed to FTG, so that it
appears that the marginal gain of such a deployment is small.

The data from the deployment of three teams to NAVSTA, NORIS and Fuel Pier may be used to support further conclusions. It is noted that the team based at the Naval Station incurs responsibility for an expected sixty-seven percent of the spills, all of which occur at the Naval Station. The team at North Island is responsible for spills at North Island, at mooring buoys and in the area of the Navy Pier. Taken together, these areas account for twenty-three percent of the expected spills and are spread over a large area. The team at the Fuel Pier is responsible for spills occurring at the Fuel Pier, at Ballast Point and at FTG. FTG accounts for only one percent of the spills and is over 1.5 nautical miles from the Fuel Pier. Ballast Point is approximately 0.75 miles from the Fuel Pier. This suggests that the largest and best-equipped team should be at the NAVSTA. The team at NORIS must be particularly capable of rapid deployment and should be equipped accordingly. If the team at NORIS were assigned responsibility for spills in the area of FTG, the increase in the measures of effectiveness would be small (less than one percent) while equipment requirements for the team at the Fuel Pier would be reduced. By concentrating on speed of deployment from NORIS, personnel training, as well as equipment allocation, can be used most efficiently.

The model used for this analysis appears valid and can be of value when considering placement of oil spill recovery equipment and personnel. The value of the model would be enhanced by availability of accurate data concerning the

size of oil spills and the elapsed time between spill and
arrival of recovery teams from various locations. It is
emphasized that the model is based upon past oil spills,
so that oil spill data should be monitored in order to
ensure that the conclusions drawn from the model remain
valid.

IV. SURVEY OF DEVICES AND METHODS FOR OIL SPILL CONTROL

The many techniques and devices which have been sug-
gested for control of petroleum products spilled onto the
water may be divided into seven general categories.[1] These
categories and the particular devices and techniques within
them vary in their applicability to spills in harbor waters.
Discussion of each category is presented, but those that
appear most effective for harbor use are emphasized.

A. CONTAINMENT BOOMS

Three types of booms--mechanical, pneumatic, and chemi-
cal--have been employed in order to contain a spill or
prevent the spread of a slick in a particular direction.
The mechanical boom is most commonly used and a detailed
discussion of this type is given in Chapter Four, Section E.

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[1]Walkup, et al, "Study of Equipment and Methods for
Removing Oil From Harbor Waters" cites six categories,
to which this chapter adds the category "Containment
Booms."

Several unique advantages are derived from the use of a pneumatic barrier. For this type, compressed air is piped beneath the surface and released along the line where the barrier is desired. The rising air creates a region of lower density above the pipe, which in turn causes a current upward which splits and flows away on either side perpendicular to the line of the pipe. Such a barrier allows free passage of ships and small craft without breaking the integrity of the barrier. The barrier is immune to fire and can contain burning oil. Such a barrier must generally be custom designed for a particular location, however, and involves significant installation and maintenance costs. Pneumatic barriers have been shown to fail in currents as low as 0.7 knot [Milz, 1970]. There are two sites in San Diego where pneumatic booms appear useful. These are the Naval Station and Fuel Pier. The former would require a very large installation, however, and the latter has had few spills in the past to justify such an expense. A pneumatic boom should be considered for the proposed refueling pier recommended in Chapter Nine. Although the use of pneumatic booms appears limited in San Diego at this time, their potential should not be overlooked.[2]

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[2]The advantages and disadvantages of pneumatic booms are discussed in a report prepared by the Maine Port Authority "Testing and Evaluation of Oil Spill Recovery Equipment" dated December, 1970, and by Walkup, et al, "Study of Equipment and Methods for Removing Oil From Harbor Waters" dated August, 1969.

The chemical boom works by rapidly spreading a mono-
molecular film over the water which displaces and concen-
trates the oil. Only a small amount of material is required
to displace oil from a large area. One of the commercial
materials of this type, Shell's Oil Herder, has been reported
to be effective in waves up to four feet in height [Milz
and Fraser, 1971]. The use of monomolecular or piston
films appears to be an excellent means of preventing the
spread of oil under piers. Care must be taken that the
spill is completely surrounded by chemical or mechanical
booms in order to ensure that the spill is not displaced
out of control. Application must be made to the State of
California before chemical booms may be used in San Diego
and the application must include evidence that the material
is not harmful to marine life. This latter is very diffi-
cult to prove to the satisfaction of the State and most of
the products currently available are authorized only for
emergency use. The chemical boom appears to be a valuable
tool, however, and if any material is found acceptable to
the State, license for its use in San Diego should be
obtained.

B. SORBING AND GELLING AGENTS

Sorbing and gelling agents are used to concentrate the
oil for easier recovery and to prevent spreading of the
slick. Several major oil companies have experimented with
gelling agents, but in general they require a one-to-one
application ratio and the resulting gel is difficult to

remove and process [Hoult, 1969]. None of the gelling
agents currently available appear appropriate for harbor
use.

Studies at the Naval Ship Research and Development
Laboratory (NSRDL) have shown that sorbing agents vary
widely in their effectiveness [Nagy and Schatzberg, 1971].
Wheat straw has been widely used since it is cheap and
readily available, but organic sorbents such as straw tend
to lose buoyancy with exposure to the water and are rela-
tively ineffective against lighter oils such as JP-5. Straw
has the additional disadvantage that after it has been
applied to a slick, it will seriously hamper almost every
type of recovery method. Certain high molecular weight
polymers such as polyurethane are much more effective and
their use offers several advantages. A major advantage of
the use of sorbents is that they assist the containment
effort at once and are particularly effective when used with
mechanical booms. These agents are oleophilic and hydro-
phobic, so that the problem of oil-water separation after
collection is largely avoided. Prior to initial use poly-
urethane foams may be stored and transported in liquid form
and generated on the site of a spill. After initial forma-
tion, however, the foam must be stored for reuse in solid
form. Foams are effective against oils over a wide range
of viscosity. A further advantage is the favorable ratio
of oil recovered to product used. When applied to a con-
fined slick without mixing, sheets of polyurethane foam
were found to absorb forty-six times their own weight of

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oil [Milz and Fraser, 1971]. Foams may be used safely in
close proximity to small craft and structures and their
performance is not seriously degraded by debris in the water.

There are three significant disadvantages to the use of
sorbents. Removal of the sorbent material after it has
become saturated with oil is messy and requires considerable
labor with the techniques currently available. Since the
acquisition cost of the sorbent is high, some device must
be employed to squeeze out the sorbent after recovery in
order to allow reuse. Prices vary with the size of the
order, but may be expected to be approximately fifty cents
per pound [Walkup, et al, 1970]. Finally, sorbents are less
effective against small concentrations of oil and their use
requires considerable time and effort in the final stages
of the recovery.

C. PHYSICAL RETRIEVAL DEVICES

There are four main groups of techniques used to
physically retrieve oil from the water. The most common by
far is intensive application of manual labor along with
sorbing agents. While this method is slow and relatively
expensive, it can be applied in such a variety of circum-
stances that it will never be entirely supplanted. The most
effective attack on a spill is rapid containment by boom
followed by application of a sorbent which is then raked,
shoveled, or scooped into recovery vehicles by manual labor.
The large amount of manpower available at Naval activities
in San Diego is an important resource for oil spill control,

although the opportunity costs such as neglect of their regularly assigned duties must be considered. (See Chapter Ten where these costs are considered and it is concluded that the Navy should seek a containment capability only and leave cleanup tasks to a contractor.)

Suction devices mounted on piers, trucks or small craft are employed in several locations to remove oil from the water. Flexible piping and flotation gear allow placement of the suction head up to 500 feet from the pump, but the large amount of water collected makes suction devices most effective only against relatively thick slicks. Debris and heavy oils may block the suction head and degrade performance. The action of the pump may emulsify the oil making subsequent disposal more difficult. Despite these disadvantages, suction devices are relatively inexpensive and widely used. The Naval Station at San Diego is currently relying upon a suction head developed by the Naval Civil Engineering Laboratory (NCEL). Continued developments by civilian and military organizations may well overcome the current disadvantages of these devices.

Another common retrieval device is the gravity skimmer or weir. These devices have a large sweep rate, but they are extremely sensitive to wave action and debris. Since skimmers depend upon forward motion for operation, they are not particularly effective in restricted waters. Their popularity may be explained in part by the fact that they are frequently fabricated from local materials at small cost.

Most of these devices collect a large amount of water along with the oil.

A great deal of publicity has been given to retrieval devices employing some combination of rotating drums or endless belts. Some of these employ metal surfaces to which the oil adheres, while others use rollers made of some sorbent material. In either case, the roller or drum is cleaned during the cycle and returns to the slick. These devices are reported to collect a high proportion of oil to water and may have a large capacity, but they are generally slow, relatively expensive and, in many cases, difficult to maneuver. A number of these devices are being developed by various civilian firms, however, and a breakthrough may be made. It has been recommended that Naval activities not invest in sophisticated pickup devices at this time, since intensive development work is still underway on a number of systems [O'Brien, 1971].

D. CHEMICAL DISPERSION

A large number of chemical agents have been developed and used for dispersing oil into a stable emulsion which will eventually be biodegraded. The agent must be applied directly to the slick and the slick must be agitated during or after application for maximum effectiveness. These products are effective initially but in the absence of tidal flushing or continued agitation the oil will eventually recoalesce. In addition, most of these products contain compounds which are toxic to marine life or which resist

biodegradation. Dispersants are large consumers of oxygen and may adversely affect the oxygen balance of enclosed waters [Walkup, 1969]. The use of dispersants is in violation of Section 5650 of the California Fish and Game Code. Therefore, although dispersants are carried by Naval units, their utilization in other than emergency situations is not recommended.

E. SINKING AGENTS

Sinking agents are absorbent materials which are heavier than water, so that they sink the spilled oil beneath the surface. While these agents may quickly remove the evidence of a spill, natural or man-made turbulence, such as boat wakes, will cause the oil to be released. Shellfish and other marine organisms may be endangered. Most sinking agents are rather bulky and therefore are difficult to transport and apply to a slick. Most agents are not effective against lighter oils such as JP-5. Sinking agents are also prohibited by Section 5650 of the California Fish and Game Code. It is concluded that sinking agents are not suitable for harbor applications.

F. BURNING

Removal of oil by burning in place on the water has been attempted in the case of a few open ocean spills. The method has not been very successful, since the water on which the oil is floating draws heat away so quickly that combustion cannot be supported. Some sort of chemical or

mechanical wick is usually required to start combustion,
although JP-5 may be flammable if contained. The problems
of air pollution and danger to harbor structures and
ships make this method largely inappropriate for harbor
use.

G. NATURAL OR ENHANCED BIODEGRADATION

Studies have suggested that if the oil were properly
contained it might be treated by application of some
organism known to be highly active in the type of oil
spilled [Walkup, 1969]. While this is an interesting idea,
it is considered too slow a technique for application in
harbor spills.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Among the most important factors which determine the
cost or damage incurred by the spill of oil onto harbor
waters are the size of the spill and the time elapsed
between the spill and the initiation of recovery efforts.
Accurate data concerning these two parameters for spills
which have occurred in San Diego was unavailable. The
available data is described in Chapter Seven of this report.
Assuming that time is proportional to the distance from
recovery team site to the spill location, the team locations
proposed by COMELEVENINST 6240.1 Draft are the most cost-
effective of those examined in this report. The team

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located at the Naval Station may be expected to be confronted by the most spills. While speed of deployment should be emphasized for all three teams, it is particularly important that the team at North Island be equipped and trained for rapid deployment since they are closest to a wide area of potential spills including the high-value installations of Harbor and Shelter Islands. The team at the Fuel Pier is responsible for a small area which may be expected to incur relatively few spills and may be equipped accordingly.

The most effective equipment and techniques currently available for combating the effects of oil spills are rapid containment by mechanical booms followed by manual recovery assisted by polyurethane foam. Each recovery team should be equipped with mechanical booms with skirts of at least eighteen inches depth capable of rapid deployment (see Chapter Four). The lack of data concerning expected size of spills makes specific equipment recommendations difficult. From the data given in Chapter Four, a 1500 foot boom could be expected to encircle 12,750 gallons of distillate fuel after initial spread in still water. Since current or wind effects tend to move a slick, it is likely that 1500 feet of boom carefully and rapidly placed by trained personnel can contain most slicks. It is the current relative to the boom which may cause failure of the boom to contain oil, so that the techniques used for handling the boom in current will determine success or failure.

Sorbent material should be applied to a slick as soon as possible. The polyurethane foams appear to be the best material, whether applied in sheets, or shredded and spread by a hay spreader. The sheet form offers advantages in handling and recovery. With the conservative estimate that twenty pounds of oil may be recovered by each pound of absorbent, 177 pounds of absorbent will recover 500 gallons of Navy distillate.

When licensed by the State of California, the use of monomolecular films to augment mechanical booms and protect piers, ships and other installations is warranted. Dispersants, sinking agents, gelling agents and straw are not appropriate materials for combating the effects of harbor oil spills. Procurement of sophisticated oil recovery devices does not appear advisable at this time.

B. RECOMMENDATIONS

The following specific recommendations are made:

1. Oil recovery teams should be established at the locations proposed by COMELEVENINST 6240.1 Draft. The team at the Naval Station should be given priority in men and equipment. Equipment and training of the team at North Island should emphasize speed of response.

2. All teams should train frequently for rapid deployment of containment devices in all of the current and wind conditions common to their areas of responsibility.

3. Each team should be equipped with 1500 feet of boom with at least an eighteen inch skirt (see Chapter Four). Each team should also be supplied with 200 pounds of polyurethane foam and equipment for its spread and recovery.

4. Efforts should be made to obtain permission of the State of California for the use of monomolecular films.

5. Attention should be paid to commercial development of sophisticated oil recovery equipment, although procurement is not recommended at this time.

6. Data from oil spills should be monitored in order to assess the effects of spill-reduction policies and ensure effective allocation of oil spill control resources.

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APPENDIX A

THE SHIPBOARD SEWAGE TRANSFER ASSEMBLY - BASIC SYSTEM CHARACTERISTICS AND DESIGN PARAMETERS

I. GRINDER/TRANSFER PUMP

The grinder/transfer pump utilized in the design of the SSTA unit is based upon a product of Environment/One Corporation of Schenectady, New York. This model, or any comparable pump system, can be utilized as long as it meets the set standards for the SSTA unit and meets required military specifications. The following characteristics of the Environment/One grinder pump will be utilized as guidelines for eventual detailed design and purchasing [Environment/One, 1971].

1. The pump is capable of delivering 15 gallons per minute (GPM) over large distances at zero head. It can deliver 11 GPM against a total dynamic head of 81 feet. The large distance of run is desirable to account for the possibility of the pierside sewage intake or a sewage barge being a considerable distance from the ship.

2. The pump will be driven by a one-horsepower motor, requiring a single phase, 240 volt, 10 amp, 60 Hz electrical supply.

3. The pump is a custom design vertical rotor confiruration that will handle solids and is equipped with mechanical seals.

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4. The grinder impeller is accurately balanced and securely fastened to the pump motor shaft. The grinder is positioned immediately below the pumping elements and is direct-driven by the same shaft. The grinder is of the rotating type with a stationary hardened and ground stainless steel shredding ring spaced in accurate close annular alignment to the driven impeller assembly, which carries two hardened precision-made stainless steel cutter bars. This assembly is dynamically balanced and runs without objectionable noise or vibration over the entire range of operating pressures.

5. The grinder is positioned in such a way that solids are fed into it from the bottom in an up-flow direction, so that there can be virtually no possibility of gravity-caused overloading or jamming.

6. The grinder is capable of reducing all components in normal domestic sewage including most anticipated foreign objects to finely divided particles which will pass freely through the passages of the pump and the $1\frac{1}{4}$-inch diameter discharge piping to which it will be connected.

7. The motor is characterized by high starting torque. It is capable of continuous duty at maximum rated pressure without tripping related overload safety devices.

8. The pump is equipped with a gravity operated, flapper-type, integral check valve, built into the

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discharge elbow. This valve provides a full-ported passageway when opened.

9. Necessary controls shall be located adjacent to or mounted on the storage tank.

10. Inherent protection against running overloads or locked rotor conditions for the pump motor will be provided by the use of an automatic reset integral thermal overload protector incorporated into the motor.

11. An overflow indicator alarm will be mounted near or on the storage tank.

12. An inverted air bell or other triggering mechanism will be connected to synchronize the operation of the pump with variations of wastewater level in the tank.

II. PUMP FLOW RATES AND TRANSFER TANKS DESIGN PARAMETERS

The SSTA unit was designed to collect and transfer human waste from a ship to a shore or barge receiving facility. As a basis for a workable design, a DD-710 class destroyer was chosen as the working model. This class was selected with the following considerations in mind:

1. The present age and limited life expectancy of the existing ships in this class.

2. The number of ships in this class that are still in operation.

3. The limited availability of ship's interior hull space.

4. The large amount of work completed by various groups on this type ship for installation of a centralized holding/transfer system makes a comparison possible.

For further design work, the after crew's head was also chosen to be the focal point of the problem.

To determine the number and sizes of pumps and storage space, it was necessary to estimate the flow-rates of a typical crew's head. Since the basic characteristic of the unit is small holding capabilities, the problem of surge conditions exists. A small tank for effective pump utilization and surge containment was decided to be a vital aspect of the unit.

The following flow-rates are estimates of expected peak time conditions (Reveille to 0800). It is further assumed, for Table A-1, that all members of the after crew's quarters utilize the head facility at least once, and that no one is on watch or on liberty.

Assuming that one-half of the crew uses the head twice, then the flow-rate into the tank is approximately 900-950 gallons per hour (GPH). Based upon average pump operation, the flow-rate out of the pump is between 750-800 GPH. Realizing the difference between the two flow-rates, a storage capacity of 150 gallons is necessary. To account for

TABLE A-1

Transfer Tank Design Parameters

After Crew Complement	125 Men
Number of Urinals	4 Fixtures
Number of Commodes	6 Fixtures
Assumed Average Discharge of Each Fixture	5 Gallons
Assumed Average Period of Commode Usage	3 Minutes
Assumed Average Period of Urinal Usage	1.5 Minutes
Flow-rate of Six Commodes	10 GPM
Flow-rate of Four Urinals	13.3 GPM
Discharge if All Personnel Use Commodes Once	600 Gallons/Hour
Discharge if All Personnel Use Urinals Once	800 Gallons/Hour
Total Discharge for Both Facilities	1400 Gallons/Hour
Minimum Pump Flow-rate	11 GPM, 660 GPH
Maximum Pump Flow-rate	15 GPM, 900 GPH
Average Pump Flow-rate	13 GPM, 780 GPH

any strong fluctuations about the average, a tank of approx-
imately 200 gallons was chosen. For a pump of higher
volumetric flow-rate or if the system is servicing a smaller
number of fixtures, a smaller holding tank can be incorporated
into the system.

III.   STORAGE TANK CONFIGURATIONS

The size of the storage tank is based upon calculations
of surge and pump operations. Defining a need for 200
gallons, leads to a tank of approximately 30 cubic feet,
internal volume.

Each tank will be constructed of medium steel, according
to the requirement of 9110-0 and 7290-8 of the general
specifications. The inside surface will be free of struc-
tural members and will be coated to prevent corrosion as
specified for sanitary tanks in NAVSHIPS Technical Manual,
Chapter 9190.

Two possible tank configurations are recommended,
depending on the size of the compartment in which the unit
is installed. Tank "A" is rectangular in cross section,
as shown in Figure A-1. An access hatch is installed to
permit freedom of maintenance and repair. The interior
bottom is sloped approximately 1.5 inches per foot towards
a sump basin at the pump suction.

The tank is configured to allow free access to the
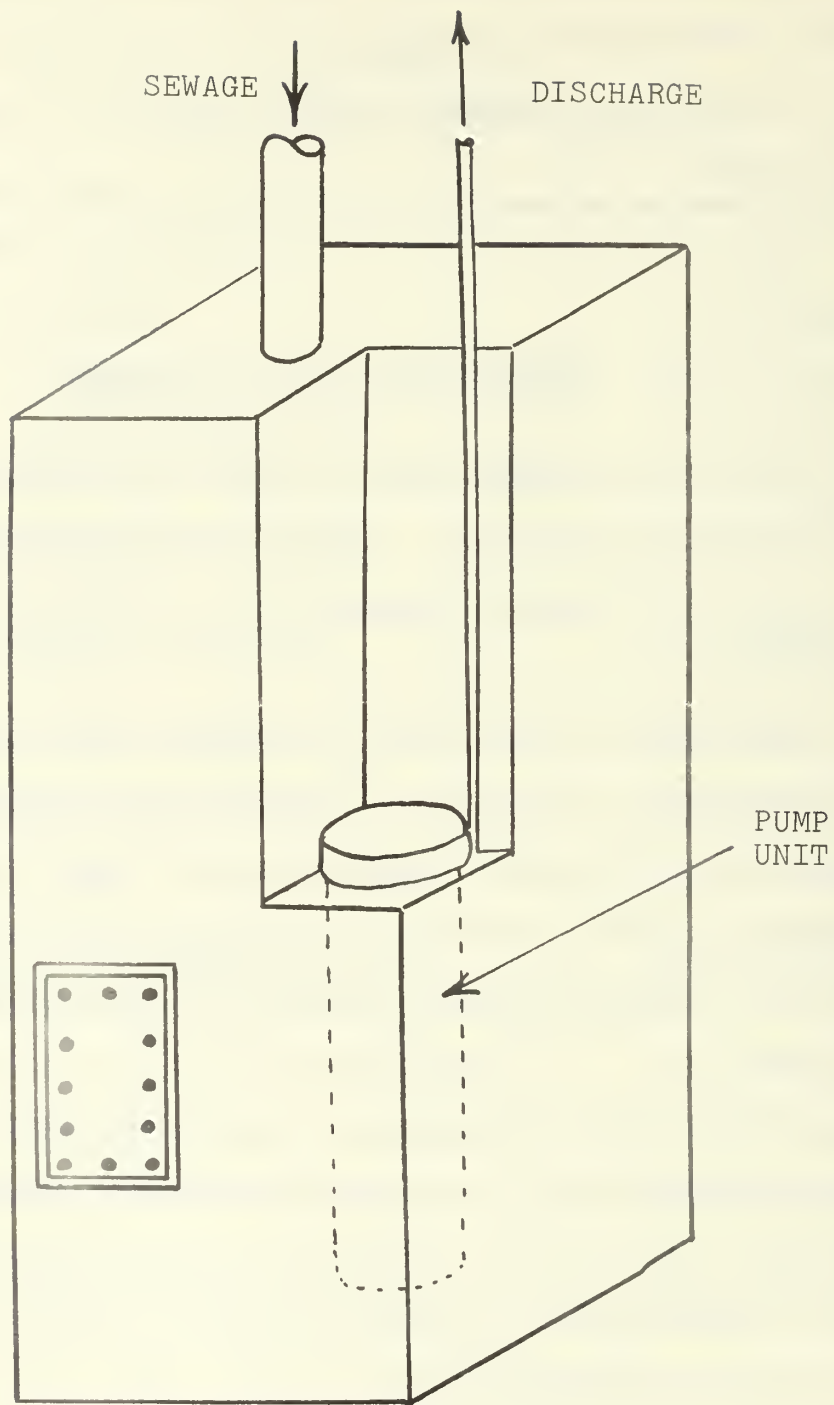grinder/transfer pump for required maintenance and repair.

SEWAGE ↓　　　　DISCHARGE ↑

PUMP
UNIT

Figure A-1.　Storage Tank "A".

The grinder/transfer pump can be removed as a unit for repair
and replaced with a spare assembly. A bottom drain is con-
venient for use and a small hand pump for emergency operation
will be available to empty the tank back into the feeding
gravity drain.

Tank "B", shown in Figure A-2, is also rectangular in
shape but is configured to be mounted in the overhead. All
of the detailed internal characteristics of tank "A" pertain
to model "B" also.

IV.   EXTERNAL CONNECTORS

Two possible types of external connectors are reccom-
mended, depending upon the location of the transfer unit.

A.   WEATHER DECK CONNECTOR

This type of connector has been designed by NSEC for
usage as the discharge port for the centralized holding
tanks. [NAVSHIP Engineering Center LTR., December 1971].
This connector would be used if the discharge line pene-
trated either the weather deck or a weather bulkhead. The
hoses are installed by a cam operated locking device.

B.   WEATHER BULKHEAD CONNECTOR

Due to the location of certain head facilities, it may
be more practical to penetrate a weather bulkhead than to
run the discharge line to a weather deck. If a smooth
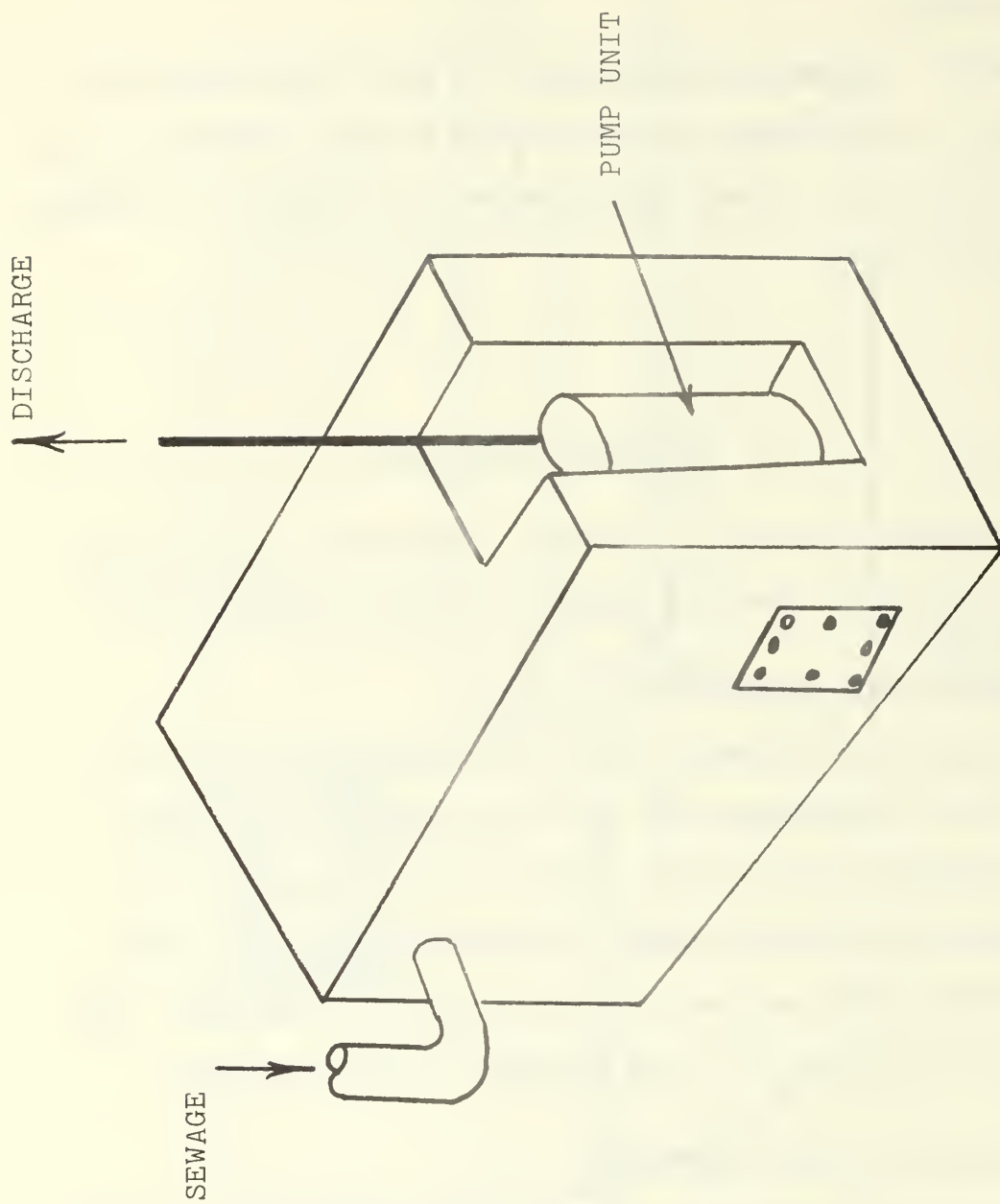
DISCHARGE

PUMP UNIT

SEWAGE

Figure A-2. Storage Tank "A".

surface is a requirement of the exit point area while at sea, then connector "B" is recommended.

The female portion of connector "B", as depicted in Figures A-3 and A-4, fits over the discharge line from the grinder/transfer pump. It is installed so that it is flush with the bulkhead and does not interfere with ship's work or machinery translation.

The male end, as shown in Figure A-5, is installed by inserting the teeth and twisting one eighth turn to align the locking holes. When aligned, a pin is inserted to hold the device in position. A water-tight seal is insured by utilization of a rubber washer and beveling of the interior teeth to force a pressure fit. The entire installation can be done either by hand or with a spanner wrench.

V. INTERNAL PIPING AND EXTERNAL TRANSFER HOSES

A. INTERNAL PIPING

All interior piping will be done according to military specifications.

B. EXTERNAL HOSES

Each ship will have the capability of discharging forward and aft via a discharge line. These lines will originate from either the weather deck or bulkhead connectors. The hoses will be $1\frac{1}{4}$ - inch, rubber, smooth bore, light weight,
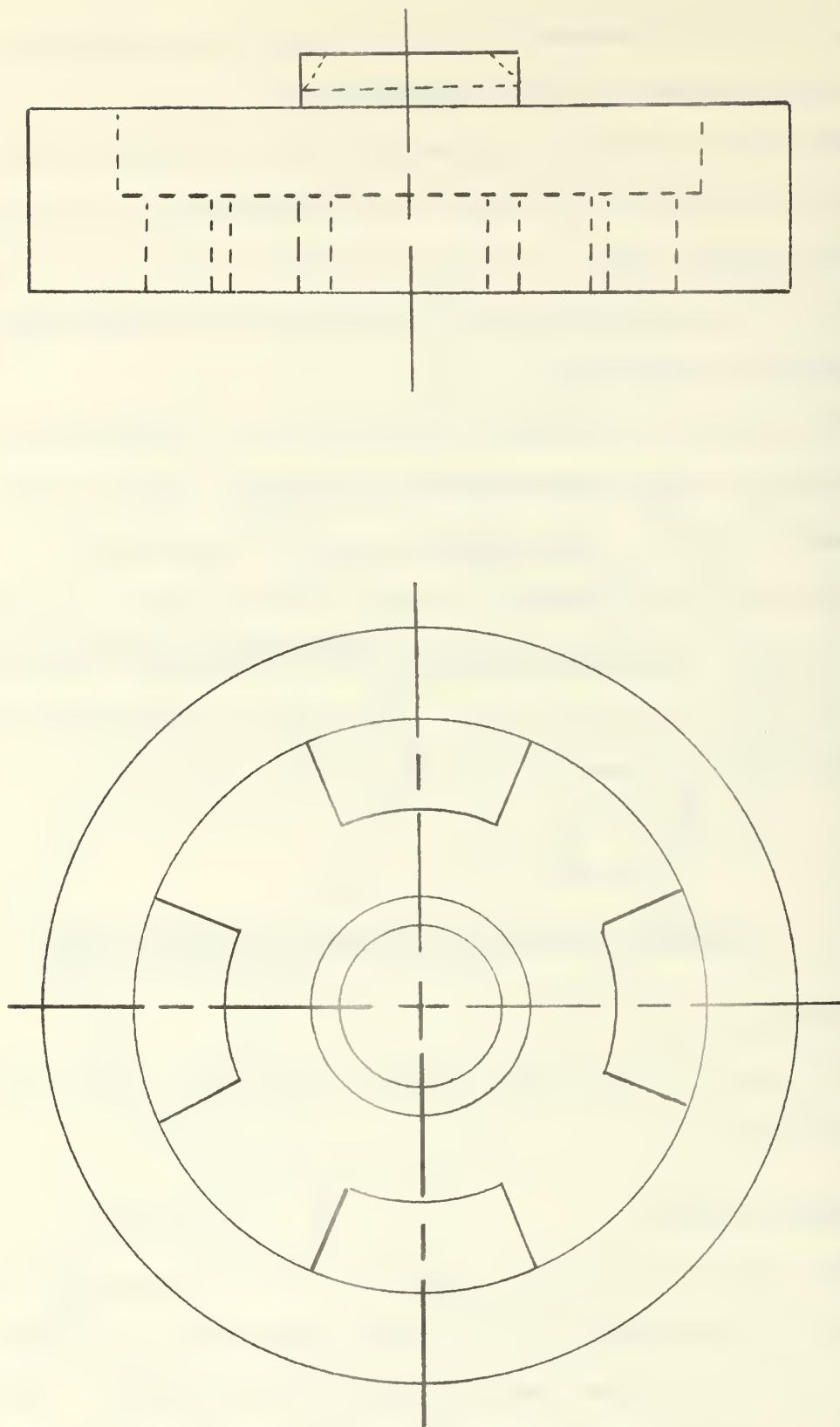
Figure A-3. Female Connector.
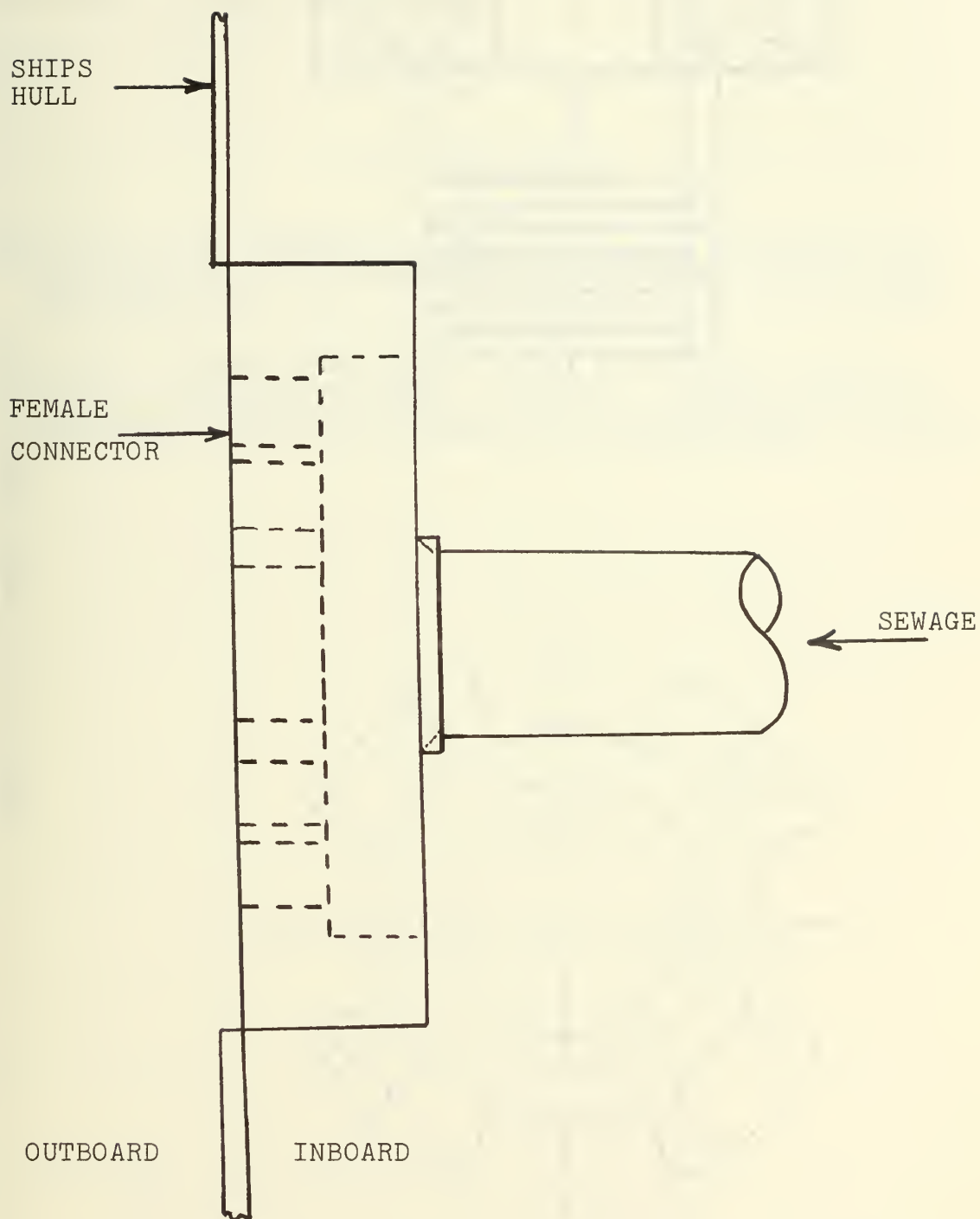
Figure A-4.   Position of Female Connector.
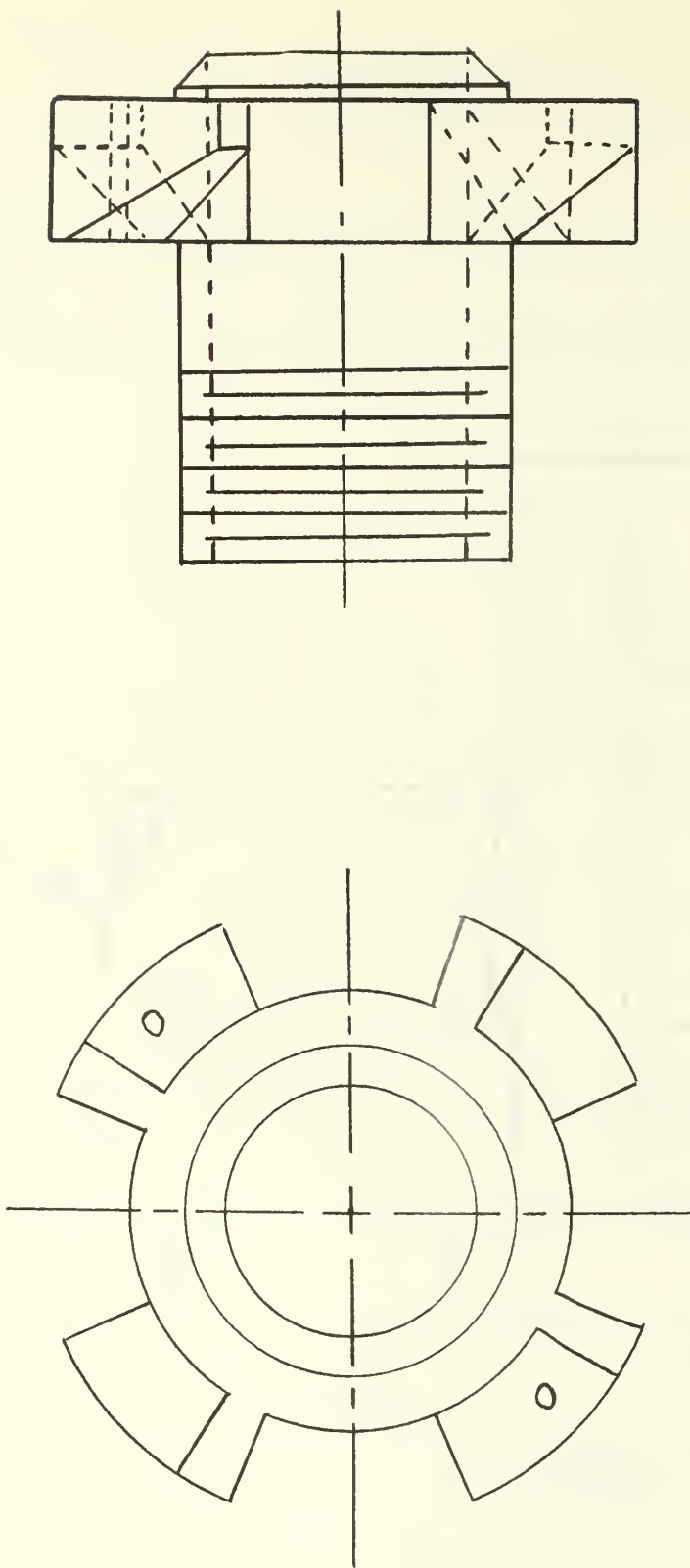
Figure A-5. Male Connector.

buoyant type hoses as specified in Mil-H-222400. Hoses will

vary in length and every ten feet the word "sewage" will

be clearly stamped on the hose.

VI. <u>BIBLIOGRAPHY</u>

Environment/One, <u>Pressure Sewers and Design Parameters for</u>
    <u>Grinder Pump</u>; Environment/One Corporation, Schenectady,
    New York.

Naval Ship Engineering Center Letter Serial 491-6159 to
    Naval Ship System Command, Subject: <u>Sewage Collection</u>
    <u>Holding and Transfer Systems for Surface Ships</u>, 23 Decem-
    ber 1971.

APPENDIX B

TABLES OF OIL SPILL DATA
AND ANALYSIS OF VARIANCE

TABLE B-1
Frequency and Monthly Cost of Oil Spills 1 July 1966—30 June 1969

1 JULY 1966 – 30 JUNE 1967

	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
FREQUENCY	11	19	16	8	5	3
COST	3948.70	6088.10	10959.80	2266.90	2085.49	1612.10

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
FREQUENCY	7	9	14	9	11	10
COST	2123.80	2952.74	9460.16	3443.50	3648.70	3429.90

1 JULY 1967 – 30 JUNE 1968

	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
FREQUENCY	3	6	7	10	6	5
COST	720.90	2977.22	1836.10	3334.30	1165.80	3783.50

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
FREQUENCY	11	4	9	11	4	5
COST	2483.00	916.70	1979.97	5626.52	2912.13	1252.40

1 JULY 1968 – 30 JUNE 1969

	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
FREQUENCY	10	6	15	9	1	4
COST	6814.42	2299.02	7035.84	1280.83	206.78	2684.45

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
FREQUENCY	8	5	5	6	3	12
COST	4218.66	3935.60	5958.84	5154.19	608.66	5284.55

TABLE B-2
Frequency and Monthly Cost of Oil Spills 1 July 1969-30 Sept. 1971

1 JULY 1969 - 30 JUNE 1970

	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
FREQUENCY	11	8	9	2	4	11
COST	3399.73	4305.16	4513.64	438.13	176.85	1951.59
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
FREQUENCY	5	7	3	10	15	10
COST	0.00	1058.03	224.35	2678.33	2029.14	1723.43

1 JULY 1970 - 30 JUNE 1971

	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
FREQUENCY	12	16	19	24	13	17
COST	6468.27	8224.43	19712.82	10298.33	6890.13	9930.31
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
FREQUENCY	14	7	22	14	12	7
COST	6821.87	175.00	6546.11	1951.30	6173.08	2453.68

1 JULY 1971 - 30 SEPTEMBER 1971

	JULY	AUGUST	SEPTEMBER
FREQUENCY	15	8	10
COST	9902.90	2599.59	9051.00

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TABLE B-3

Frequency and Yearly Cost for Ship Type and Location 1 July 1966 – 30 June 1969

	1 JULY 1966–30 JUNE 1967		1 JULY 1967–30 JUNE 1968		1 JULY 1968–30 JUNE 1969	
	FREQUENCY	COST	FREQUENCY	COST	FREQUENCY	COST
DESTROYERS	49	20943.10	26	5865.60	31	9425.66
AMPHIBIOUS	16	4799.81	9	1202.39	10	5136.00
CRUISERS	1	0.00	3	539.68	3	1485.74
CARRIERS	11	4197.69	6	3426.22	10	7563.79
TENDERS & REPAIR	7	6506.95	1	103.30	4	3691.69
OILERS	4	624.60	3	4779.01	1	0.00
OTHERS	2	1832.35	3	718.40	9	104.04
UNKNOWN	32	13115.39	31	12353.94	16	18074.92

	1 JULY 1966–30 JUNE 1967		1 JULY 1967–30 JUNE 1968		1 JULY 1968–30 JUNE 1969	
	FREQUENCY	COST	FREQUENCY	COST	FREQUENCY	COST
NAVAL STATION	97	42923.10	57	18232.11	58	32243.86
NORTH ISLAND	17	5887.65	13	5132.89	10	8520.36
BUOYS	4	715.59	5	865.20	5	2348.40
FUELING PIER	1	1166.85	2	4276.61	2	868.25
OTHER	3	1326.70	5	481.73	9	1500.97

TABLE B-4

Frequency and Yearly Cost for Ship Type and Location 1 July 1969 - 30 Sept. 1971

| | 1 JULY 1969-30 JUNE 1970 | | 1 JULY 1970-30 JUNE 1971 | | 1 JULY 1971-30 SEPT. 1971 | |
	FREQUENCY	COST	FREQUENCY	COST	FREQUENCY	COST
DESTROYERS	32	6549.22	39	14687.17	13	3846.71
AMPHIBIOUS	15	7053.19	20	7507.79	4	5917.20
CRUISERS	6	897.76	12	2657.14	1	405.11
CARRIERS	4	581.81	20	9896.19	4	3631.40
TENDERS & REPAIR	2	1263.93	9	20112.45	2	1472.00
OILERS	3	247.94	0	599.00	0	0.00
OTHERS	13	1851.23	12	1819.95	2	0.00
UNKNOWN	20	4053.30	60	28365.64	7	6281.07

| | 1 JULY 1969-30 JUNE 1970 | | 1 JULY 1970-30 JUNE 1971 | | 1 JULY 1971-30 SEPT. 1971 | |
	FREQUENCY	COST	FREQUENCY	COST	FREQUENCY	COST
NAVAL STATION	60	14358.30	85	47986.51	23	15098.32
NORTH ISLAND	14	4317.83	47	31690.79	7	5698.42
BUOYS	12	746.46	12	2926.85	2	0.00
FUELING PIER	1	0.00	7	733.40	0	0.00
OTHER	8	3075.79	26	2307.78	1	756.75

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Method for Testing Polynomial Models

The linear equation is examined by testing the hypothesis $b_1 = 0$ with an F test. Since the computed F value exceeds the critical value at the 95% level from an F-distribution table, the hypothesis is rejected with a risk of being wrong of less than 5%. The quadratic is tested in the same manner with a hypothesis $b_2 = 0$. This is accepted since the calculated F value is less than the critical. Since some statisticians recommend that two consecutive acceptances appear before the problem of the degree of polynomial can be settled [Graybill, 1961], the cubic is examined and the hypothesis $b_3 = 0$ is accepted. It is therefore concluded that a linear polynomial provides the "best" fit for these data.

TABLE B-5

Analysis of Variance for Testing Polynomial Models

	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SUM OF SQUARES	CALCULATED F	CRITICAL F	OUTCOME
Linear Term	1	400451328	400451328	69.30	4.00	$b_1 \neq 0$
Linear Error	61	352485120	5778444			
Quadratic Term	1	642048	642048	0.11	4.00	$b_2 = 0$
Quadratic Error	60	3518843072	5864051			
Cubic Term	1	14860800	14860800	2.60	4.00	$b_3 = 0$
Cubic Error	59	336982272	5711563			

BIBLIOGRAPHY

Graybill, F. A., _An Introduction to Linear Statistical Models_, McGraw-Hill, pp. 166-171, 175, 1961.

APPENDIX C

EQUIPMENT

I. GAS CHROMATOGRAPH

The gas chromatograph used in all experiments reported by this group is a Bendix model 2200, employing a column 1/8-inch by 96 inches, filled with 20% SE 30 on Chromasorb W. Injection ports were maintained at 200°C, with flame detector at 150°C. Carrier gas was helium, passed at 50 cc/min. Chart speed was 30 in/hour. Individual time/temperature programs are given in each experiment description.

A. PRINCIPLES OF OPERATION

The heart of the gas chromatograph is a long tube called the column (Figure C-1). This tube is filled with a fine granular material like sand, which has been specially treated as follows. Based on the use to which the column will be put (that is, what sort of materials are to be analyzed), a non-drying liquid is selected to coat the granular material. The coating used for this study was SE 30, a silicone oil, used for general purpose work.

The basic principle used in the gas chromatograph is that different molecules have different solubilities in a given liquid. The principle is employed as follows: as a sample is injected by syringe into the inlet port of the chromatograph, it is immediately raised to a high
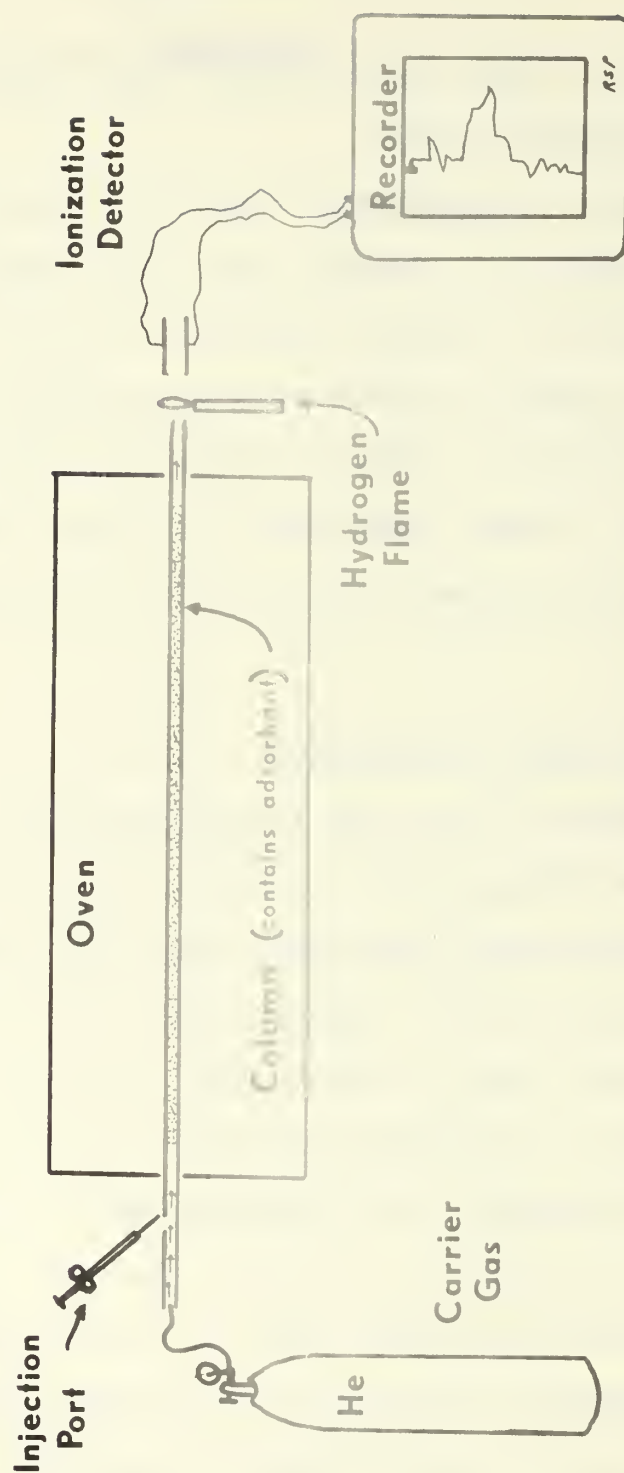
Figure C-1. Gas Chromatography Anatomy.

temperature and exposed to the carrier gas. The carrier gas, a stream of pure helium, passes constantly through the entire length of the column. The injected sample possesses, due to its temperature, a fairly high vapor pressure. Molecules from the sample pass into gas, tending to balance this vapor pressure and prevent further evaporation, but the carrier gas whisks them away before an equilibrium pressure has been established. Finally, therefore, all the molecules in the sample will pass into a gaseous state and be carried into the column proper.

The column is filled with grains coated with liquid, but with spaces between the grains permitting a continuous flow of carrier gas. As each molecule of the sample is carried downstream by the helium, it contacts this liquid. For each specific type of liquid and molecule shape, there exists a solubility coefficient, K, which expresses the tendency of the molecule to go into solution in the liquid rather than remain gaseous. The value of K is never zero in either direction, that is, no molecule will fail to dissolve at all in the liquid; neither will a molecule always remain gaseous. Therefore, if a sample of two types of molecules enters the column, each will have a tendency to dissolve in the liquid, but to differing extents due to the value of K for each. However, since the dry carrier gas flows constantly, equilibrium is never reached. As soon as some of the gaseous molecules near a grain dissolve in an attempt to balance the gas-liquid phase distribution, the helium

removes the remaining gaseous sample molecules from the
vicinity. The molecules in solution then must evaporate in
an attempt to restore the equilibrium, and soon all molecules
dissolved in the liquid around a particular grain have
evaporated.

The sample thus continues on through the column, with
each molecular species dissolving, evaporating, and dissolv-
ing again as it moves downstream. Variations in K for
different species lead to a tendency to spend either more or
less time in the gaseous phase, and progress is speeded or
retarded accordingly. In addition, the column is contained
in an oven, which is cycled by a controller to provide a
time/temperature relationship dictated by the experimenter.
Since K is affected by temperature as well as liquid selec-
tion, the experimentor has another variable to use as an aid
in separating species of molecules.

Eventually the molecules of each species reach the end
of the column and enter the flame detector. This consists
of a pair of metal plates wired to electrical contacts,
positioned above and around a hydrogen flame. Molecules
leaving the column are burned by the hydrogen flame and
break down into characteristic decomposition products, which
pass between the plates of the detector. As they do so,
the products form a dielectric between the plates, which
are wired in an electrical circuit as a capacitor. Changes
in the dielectric cause changes in capacitance, which are
sensed, amplified, and used to drive a pen recorder which

provides a graphic record of signal versus time. Since the continuous evaporation and dissolving of a species depends on random motions of molecules, each species arrives at the detector in a Gaussian distribution, producing a peak on the recorder paper.

An alternate method of turning the arrival of the molecules at the end of the column into a pen recording is the thermal conductivity device. Basically, the device measures the amount of heat carried per unit volume as each molecular species passes the detector.

B. ADVANTAGES

The primary advantage of the gas chromatograph is that it can produce a characteristic trace from an extremely small sample of material. The standard sample size used by this group was 0.0003 ml, or far less than a drop. The procedure is simple and can be completed at various speeds, depending on accuracy desired. Accuracy is correlated with separation of peaks from different molecules, and is regulated by heating the oven more or less slowly and use of appropriate column materials. Tests used by this group averaged 30 minutes in length.

C. DISADVANTAGES

The main disadvantage in the use of the gas chromatograph is the effort needed to identify the molecule which produced a peak. By noting the exact temperature at which it appeared, reference can be made to a handbook for a start on identification. Confirmation can be attempted by adding a known

solution to the sample to be analyzed; comparison of known
peak positions with those of the unknown sample may show its
identity. But unfortunately there is no way to be absolutely
sure that a given peak is a certain molecule and not another
which happens to have the same solubility characteristics on
that particular type of chromatograph column filler material.

Another uncertainty is introduced by use of the flame
detector. Any attempt to use the chromatograph for quanti-
tative work, noting relative amounts of molecular species
within a sample, must allow for the fact that depending on
the nature of its decomposition products, a given number of
molecules may make more or less change in the detector
capacitance than another species. Halogens, for example,
may produce decomposition products in the flame detector
which do not change the dielectric constant, and hence are
not observed at all.

II.   FLUORIMETER

The G. K. Turner Associates model 210 Spectro-Fluorimeter
was used for all experiments reported by this group. This
machine has the capability to continuously vary both exita-
tion and fluorescence wavelength, as well as giving trans-
mission readings for any wavelength. Optimum exitation
wavelength for Navy Distillate oil was determined to be
290 nanometers, and this wavelength was adopted for use

with all oils tested.[1] All samples were 5 ml in size, tested in fuzed quartz cuevettes.

A. PRINCIPLES OF OPERATION

The most basic parts of a fluorimeter are a lamp to provide excitation, a sample, and photocell to measure light output by the sample (Figure C-2). Other devices, shown on Figure C-2 and described below, add to the versatility of the fluorimeter and permit it to be used to distinguish certain types of molecules from others.

The light source is a quartz-iodide lamp, chosen for its broad spectral output and constant high intensity. It shines through a transmission diffraction grating, which causes the light beam to be diffracted into a spectrum in the same way that a prism can produce a rainbow from sunlight.

The diffraction grating is movable, so that light from a particular wavelength can be caused to pass through an entrance slit and fall on the sample. Controls of this particular model fluorimeter permit varying the width of the spectrum passed through the entrance slit, as well as selection of any desired center frequency.

The principle of fluorimetry is based on the energy states of a molecule. In any given sample, the molecules can be assumed originally to be in their lowest energy state. That is, the electrons of the molecule are filling orbitals of the lowest possible energy. In addition, the molecule possesses some amount of thermal energy, expressed

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[1]Maximum exitation wavelengths for NSFO, JP-5, and diesel oil were found to be 310 nm, 275 nm, and 285 nm, but intensity of fluorescent spectrum was only slightly lower at 290 nm.
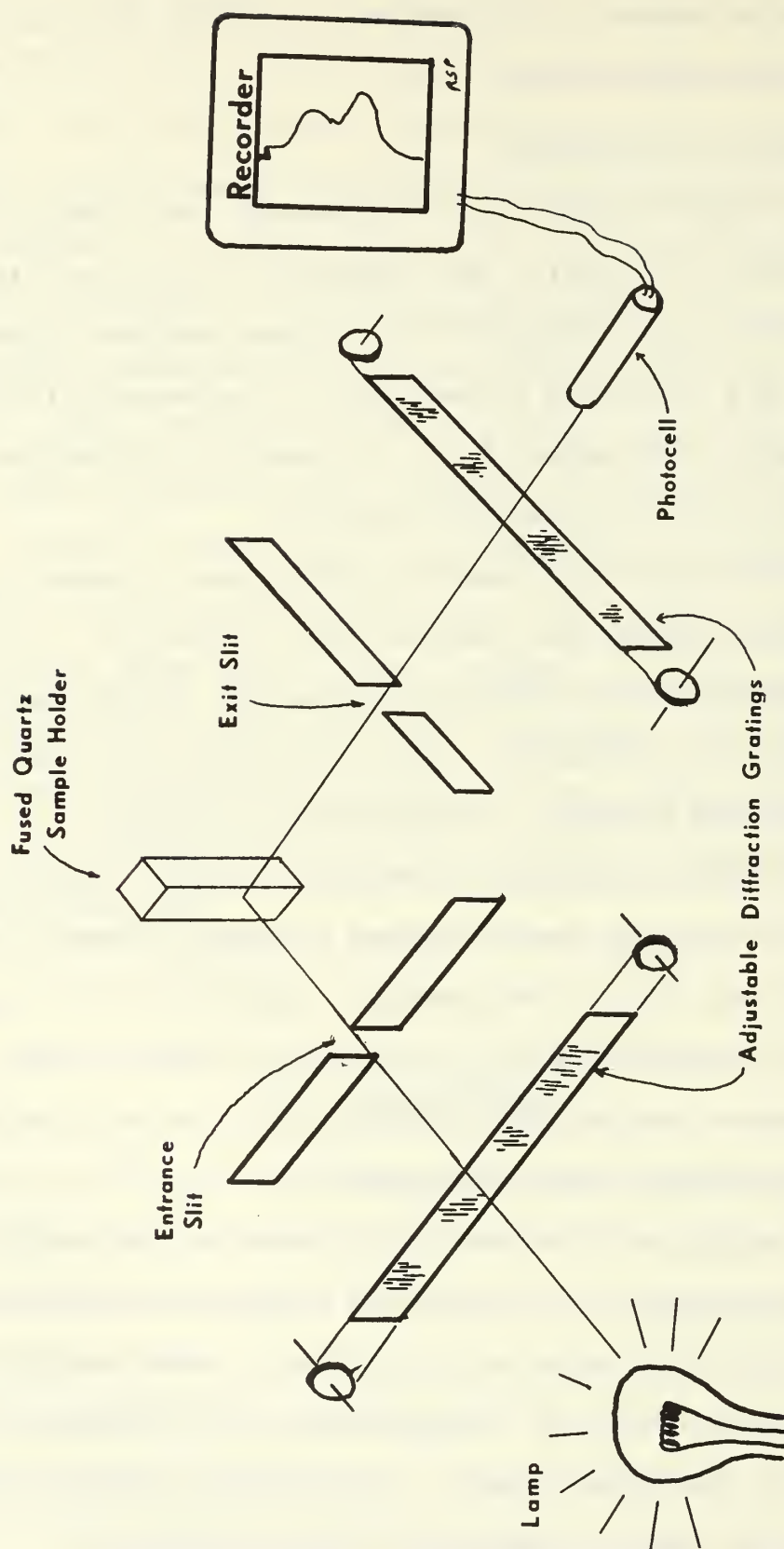
FLUORIMETER SCHEMATIC DIAGRAM

Figure C-2. Fluorimeter Schematic Diagram.

by the molecule as random vibrations. The absorption of incident light photons by a molecule momentarily raises one or more of the electrons to a higher energy level. Since these energy levels are at discrete intervals and not continuous, only photons possessing the correct amount of energy can bring about the jump. Photon energy is dependant on the wavelength of the light--thus exitation of a sample can occur only when the correct exitation wavelength is allowed to pass through the entrance slit and fall on the sample.

Excited molecules tend to return to their lowest possible energy state spontaneously. The energy of exitation may be released as increased thermal activity in which case the molecule becomes "hot" and transfers some of its energy to its neighbors by collision. For fluorescence, though, the important process for releasing excess energy requires the excited electron to "jump" back into its unexcited state, either directly or with one or more stops at other permitted energy levels. When the electron makes a jump it must release a photon of light of wavelength appropriate to the amount of energy released. Since the jump down may be made by a different route than the jump up, and since part of the energy may be lost thermally, the wavelength of the emitted light is not usually the same as that of the incident light, but it nevertheless occurs in discrete frequencies which are characteristic of the structure of the molecule.

The emitted light photons are radiated in all directions. To minimize the effect of incident light photons being

scattered into the receiver, the exit slit for light from the sample is located at 90° to the entrance slit. Beyond the slit, a diffraction grating similar to the one on the entrance side controls the frequency of light reaching the photocell. The gratings on the entrance and exit sides are motor-driven, and may be varied in wavelength either separately or simultaneously. For experiments by this group the exitation wavelength was held fixed, while the emission wavelength was varied to produce a curve showing peak emission frequencies for the sample.

The photocell receives the emitted photons which pass through the exit slit and grating, and converts these to an electrical signal to drive a pen recorder. Since neither exitation nor emission wavelength can be limited to precisely one frequency, the pen traces a smooth peak beginning as the emission wavelength starts to be passed by the grating, peaking as it is in the center of the grating exposed to the exit slit, and declining thereafter. Molecules of differing types present in the sample produce peaks at different wavelengths, and a mixture of several thousand molecular species, as in a sample of oil, may produce a broad, smooth curve in which the peaks from a given molecular type cannot be resolved.

B. ADVANTAGES

The fluorimeter can detect very small concentrations of molecules. For example, in this study traces of oil less than 5% of saturation in seawater, or about 30 parts per

million were detectable. In addition, the process is very rapid, permitting each run to take under 8 minutes, less than one-third the time required for a gas chromatograph analysis.

C. LIMITATIONS

Unfortunately the fluorimeter has limitations which add uncertainties to the procedures used in this study. The basic problem is that most molecules have stable electron configurations and do not exhibit fluorescence at all. Of the thousands of types of molecules present in a given oil, only 3 to 7 percent exhibit fluorescence at wavelengths available for study. Hydrocarbons, which make up the bulk of any oil (about 85%) do not fluoresce. This raises questions when the fluorimeter is used as reported in Chapter Five to detect oil in seawater. Although it is true that certain components of the oil were indeed present, the presence of the other constituents of the oil can only be inferred from the solution effect noted below. This is why no absolute concentrations were given for results in the mechanical agitation portion of Chapter Five.

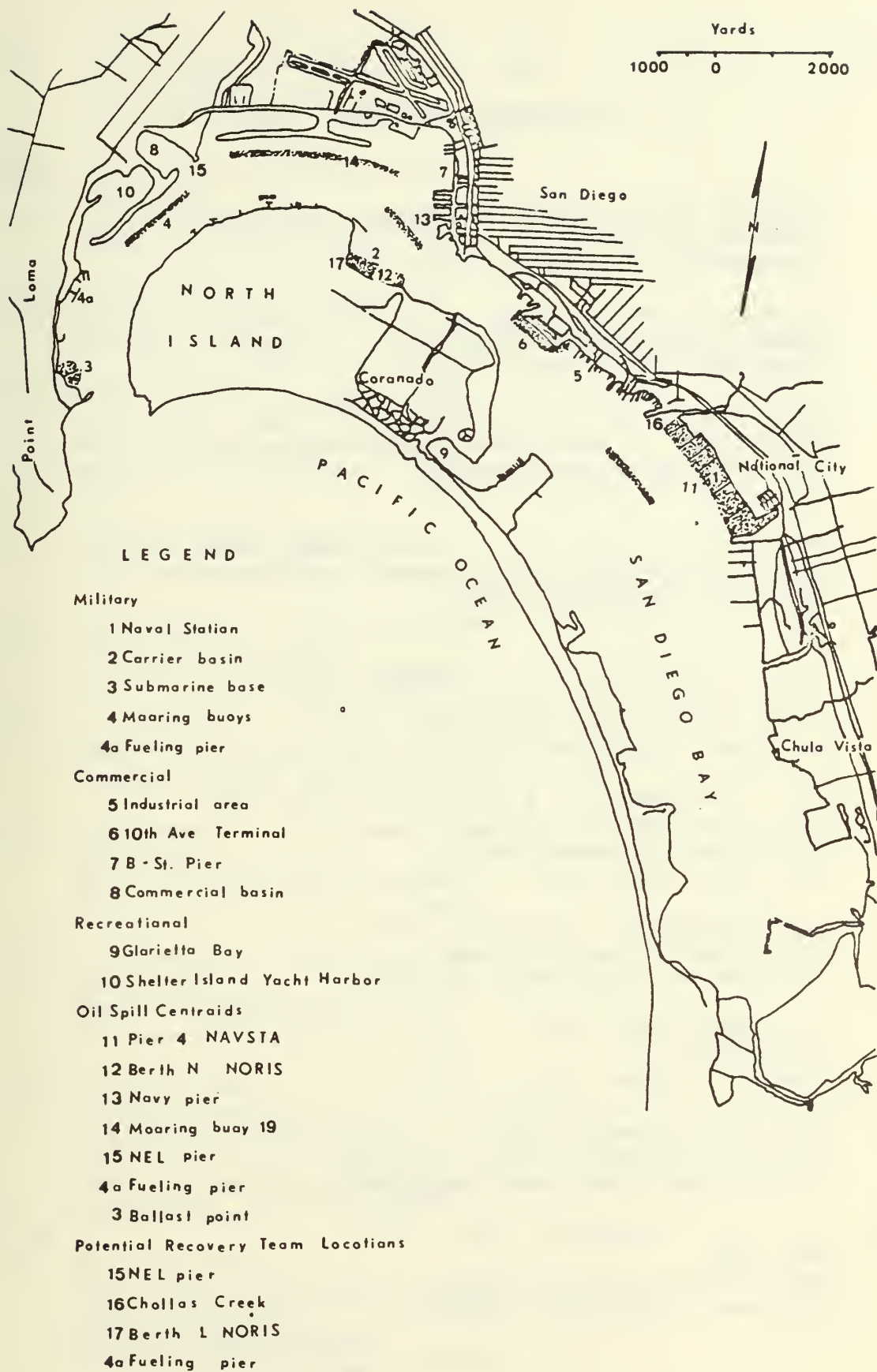Another phenomena, which can be viewed either as an advantage or limitation, is the change of emission wavelength depending on the medium in which the sample is dissolved. The disadvantage lies in that not only must the electron orbitals in an individual molecule be considered, but also their interactions with nearby molecules. For example, according to Woodward's Law, a given emission wavelength

in an aqueous solution will be shifted down 110 nanometers
if the sample is dissolved in hydrocarbons. This shift
was used in evaluation of Chapter Five data, where it showed
that detected oil molecules were in solution in oil, thus
showing that the oil was still in droplet form rather than
solution, and further showing that the other molecules which
make up the bulk of the oil but do not themselves fluoresce
were also present.

Question: Since hydrocarbons do not show fluorescence,
were they present in the dissolved oil found in the molecular
diffusion experiment?

APPENDIX D

MAP OF SAN DIEGO HARBOR

Yards

1000 0 2000

8
15
10
7
4
San Diego
13

N O R T H

I S L A N D
17 12
2
4a
Coronado
6

3 3
5
16

National City
11
9

P A C I F I C   O C E A N

S A N   D I E G O   B A Y

Chula Vista

LEGEND

Military

1 Naval Station

2 Carrier basin

3 Submarine base

4 Mooring buoys

4a Fueling pier

Commercial

5 Industrial area

6 10th Ave Terminal

7 B - St. Pier

8 Commercial basin

Recreational

9 Glorietta Bay

10 Shelter Island Yacht Harbor

Oil Spill Centroids

11 Pier 4 NAVSTA

12 Berth N NORIS

13 Navy pier

14 Mooring buoy 19

15 NEL pier

4a Fueling pier

3 Ballast point

Potential Recovery Team Locations

15 NEL pier

16 Chollas Creek

17 Berth L NORIS

4a Fueling pier

Loma

Point

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OF WATER POLLUTION FROM NAVY SHIPS

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13. ABSTRACT

    Comparison of various methods of sewage treatment and
inclusion of operational needs led to proposals for ship-
board installation of a necessary interfacing which permits
prompt response to environmental standards as they impact
on Navy ships.
    Pollution due to petroleum products from Navy ships
was found amenable to reduction by some engineering improve-
ments and changes in operating procedures for fuel handling.
Transfer of bilge water ashore seems the proper strategy
for this source of pollution. A financial analysis supports
use of civilian contractors as best option for spill
cleanup.

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